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Finer Points

SUPERABRASIVE INDUSTRY REVIEW

Polycrystalline and Diamond Composite Materials

THIS ISSUE

Education Course Review

News & Notes

PCD Bits for Underground Roof Bolting

IDA Member Companies

Measurement of Residual Stress of Polycrystalline Diamond Cutter (PDC) by X-ray Diffraction Technique

INTERTECH 2019 in New Orleans

Abrasive Wear Properties of Thermally Stable Diamond Composite Materials

Industrial Diamond Association of America & Unified Abrasive Manufacturers Association Joint Meeting Announcement

THE LONGEST RUNNING MAGAZINE DEDICATED SOLELY TO THE TECHNOLOGY AND APPLICATION OF SUPERABRASIVES

WWSA's Latest High Performance CBN Product **CBN-AMX**

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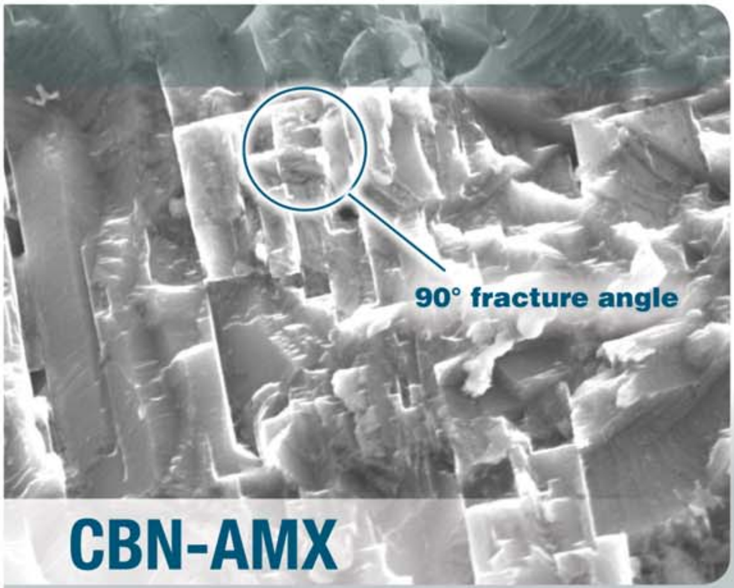
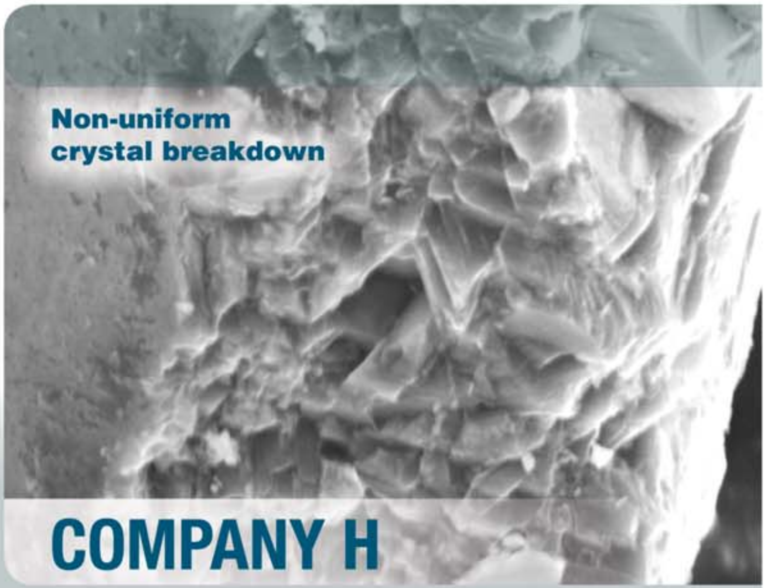
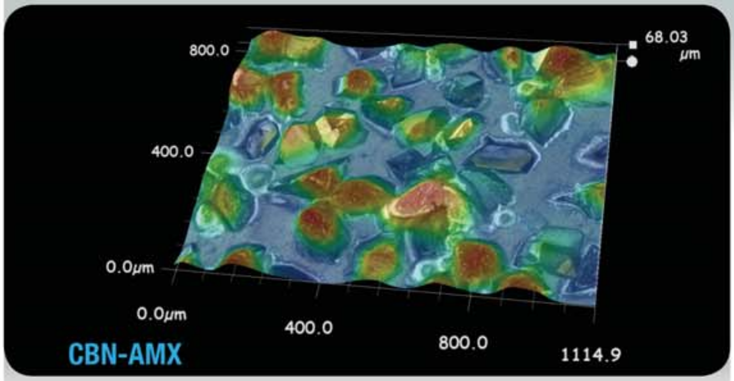
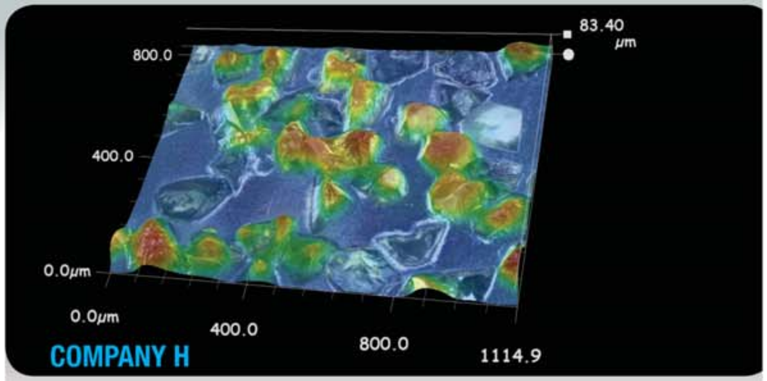


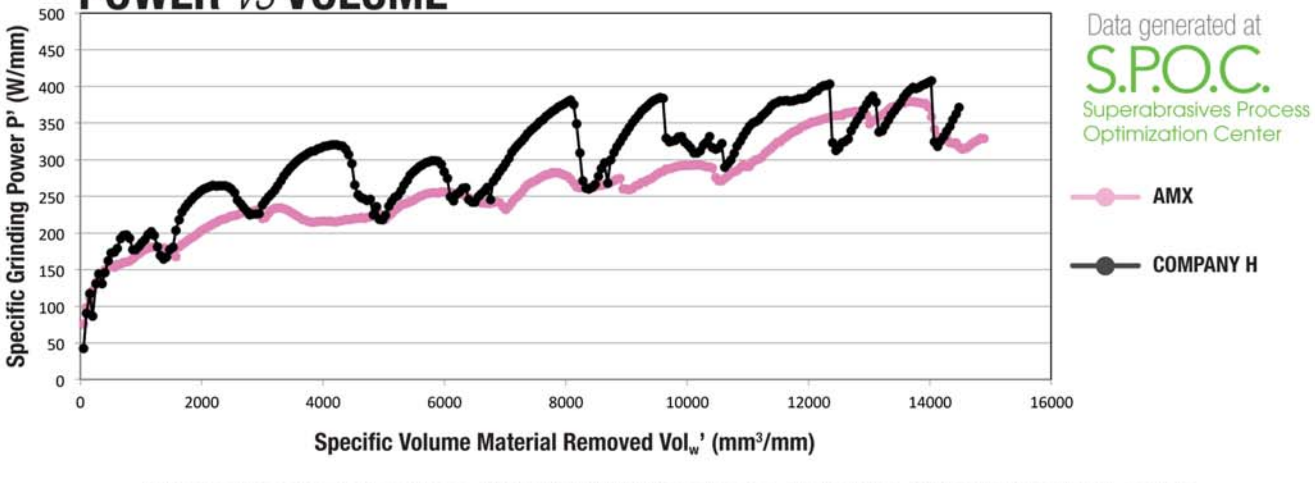


- these crystals were removed from electroplated CBN wheel's (same manufacturer) after grinding 15,000 Specific Volume Material Removed Vol ' (mm3 /mm) of Inconel 718
- note the consistent 90 degree fracture mode fracture mode for the AMX which directly relates to the long, consistent grinding cycles (note in the Power vs. Volume chart below)
- note that the AMX (Pink line) consistently draws lower power and provides a more free cutting crystal
- note that the Competitor H crystal, also removed after grinding the same amount of workpiece materials, exhibits a non-uniform crystal breakdown that is clearly exhibited in the Power vs. Volume chart





POWER *VS* VOLUME



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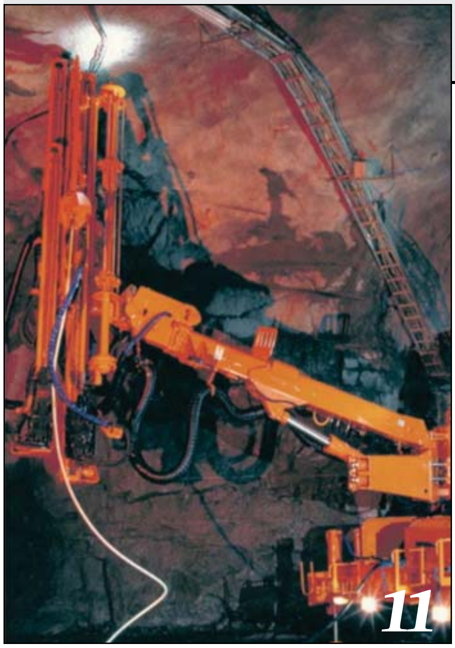


features

8 Education Course Review

11 PCD Bits for Underground Roof Bolting

18 Measurement of Residual Stress of Polycrystalline Diamond Cutter (PDC) by X-ray Diffraction Technique

23 INTERTECH 2019 in New Orleans

24 Abrasive Wear Properties of Thermally Stable Diamond Composite Materials

29 Industrial Diamond Association of America & Unified Abrasive Manufacturers Association Joint Meeting Announcement

30 The Naples Beach Hotel & Golf Club

departments

4 A Finer Point of View

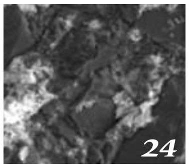
6 Editorial

9 News & Notes

10 Calendar of Events

16 IDA Member Companies

22 Ad Insertion Order



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Niabraze, LLC 29
Standard Die & Fabricating Inc. ..... IBC
Trigon Technologies 14
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COVER PHOTO

Photo courtesy of SANDVIK Mining and Construction of a continuous bolter miner showing roof- and rib bolt rigs.

FINER POINTS is the longest running publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these “superabrasives”, either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).

A Finer Point of View…

As we get to the end of another year and start 2018, I think of how thankful I am with all that has happened. Many good and bad things have affected our lives. In 2017 people have suffered from the natural disasters such as the several hurricanes that devastated many families. Tornadoes happened more frequently to the middle of our country and the wild fires fueled by the years of drought in the West. These areas will spend the next several years rebuilding with the support of the community. Then there were the shootings where a few angry people changed the lives of so many innocent people that were injured or lost their lives.

But through this we see the outpouring of people helping people. It is great to see how connected we are in America, to respond to the needs of strangers that have been less fortunate than us and how we reach out our hand to help. I want to congratulate all of you that have helped because it is the right thing to do and you do it quite often anonymously.

We all have the same 24 hours each day and we need to value our time and appreciate the time others share with us. We just completed the IDA Education Course in Charlotte, NC and I want to thank the members who taught the courses so that others can become more knowledgeable about super abrasives. This is how our organization works to bring value to other manufacturing professionals.

When we were young we felt like we had all the time in the world, yet time has flown by in our quest to build businesses and raise families. Have we made the most of our time? Have we made a difference? The world seems to move at an accelerated pace in our Internet and connected world and we wonder if we are setting the correct priorities. Make sure those around you know how much you appreciate them.

PRESIDENT
Ed Francis

Practice gratitude each and every day; wake up with a thankful heart. Stay in the present – the only time you have is the here and now. When you write down at least five things you are grateful for, the universe continues to provide more to you. Positivity erases the negative and brings much joy into your life and others. Today is the beginning of the rest of your life. You get to choose how you live it. Give back when you can and it comes back to you in ways you never expected – peace and contentment.

Make sure you get involved and make good things happen in people's lives and you will find joy and accomplishment in yours.

I hope you had a great holiday season and I look forward to all we can accomplish in the year ahead.

"There are only two ways to live your miracle life. One is as though nothing is a miracle. The other is as though everything is a miracle."
– Albert Einstein

Best regards,

Ed Francis, President
Industrial Diamond Association of America

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FINER POINTS is the official publication of the Industrial Diamond Association of America, Inc. and is published fours times a year. Contributions are welcomed but the Editor reserves the right to accept or reject any material deemed inappropriate for publication. All by-lined articles published in this magazine represent solely the individual opinions of the writers and not necessarily those of the Industrial Diamond Association. Executive and Editorial Offices: Finer Points, P.O. Box 29460, Columbus, Ohio 43229, (614) 797-2265. Editor and Advertising, Terry Kane. Advertising rates and deadlines available upon request.
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TERRY'S EDITORIAL

TERRY KANE, Editor

Those of us in the Industrial Diamond Association of America (IDA) and of course many other companies both in ours and other industries travel often and therefore stay in numerous hotels around the world. Since I am involved heavily in both meeting planning and researching sites to have our meetings and conferences I read a lot about what is going on with hotels and policies. Recently, we have seen an upheaval in security measures at hotels due to the rash of shootings. There have been numerous shots fired and reported deaths across the country, everything from self-inflicted to drug related or domestic disturbances. Of course the most shocking are the mass shootings in Las Vegas and in Manila and their outrageous accounts. In Manila the shooter stormed a casino killed 36, stole a million dollars in chips and then set himself on fire. Las Vegas involved a lone gunman, who, for no apparent reason rained a rapid-fire barrage from the upper stories of the Mandalay Bay Resort and Casino on an outdoor concert festival, leaving at least 59 people dead, injuring 527 others, and sending thousands of terrified survivors fleeing for cover, in one of the deadliest mass shootings in American history. At least 23 firearms were found in the shooters hotel suite, along with hundreds of rounds of ammunition, including two rifles outfitted with scopes and set up on tripods in front of two big windows. The result of this onslaught has brought into question, "How could a person bring such an arsenal into a hotel room without being noticed?"

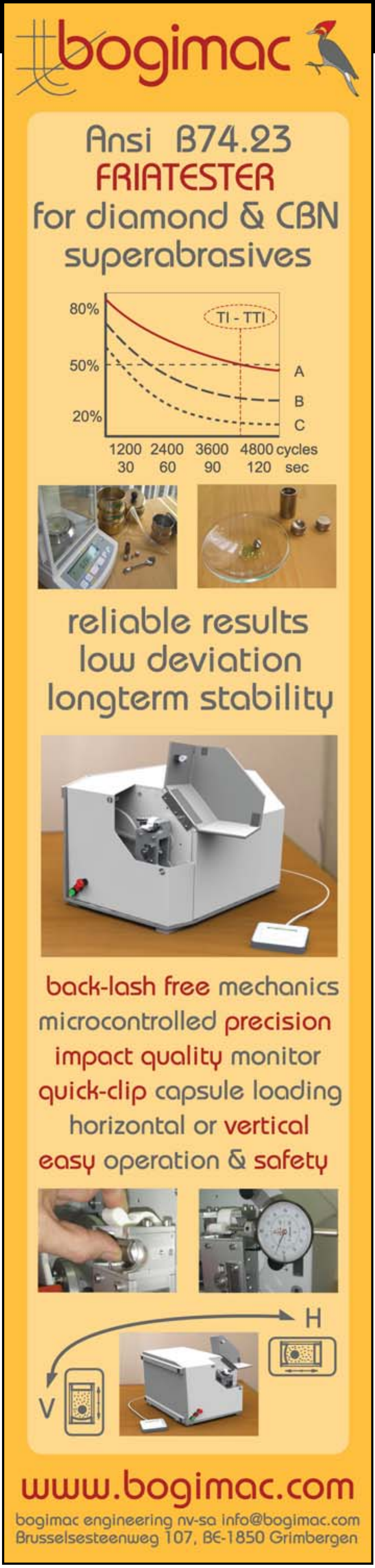
Now hotels have a new policy to eliminate the "Do Not Disturb" option for hotel guests. So the argument starts ... Do you want someone entering your hotel room without your permission? Do hotels even have the right to enforce this?

Recently, a man was arrested for allegedly trespassing and being intoxicated and with a small arsenal of guns stashed in his guest room just hours before one of the largest New Year's Eve parties at the Hyatt Regency Houston. Police determined he had "no unlawful intent" to use the firearms.

From Disney Resorts to Casinos in Las Vegas those are the core questions on many travelers' and meeting professionals' minds in the wake of updated security procedures announced in December. Several hotels along the Las Vegas Strip have tightened their room entry policies, requiring that rooms are checked on after so many hours (typically 24-48). Hilton Hotels and Resorts also recently updated its "Do Not Disturb" policy and the company is encouraging hotel employees to report any "suspicious" behavior.

Industry and Meeting Planner attorneys stress that it's well within a hotel's right to enforce room entry policies, but the frequency of such entries depends on a variety of factors. This is a growing trend, and not just a response to the Las Vegas shooting. From a legal perspective, the hotels are not exercising a new right, since most states always allow hotels to enter rooms at reasonable times for legitimate purposes such as cleaning and protecting hotel property. The new policies by Disney and others are just highlighting these rights to enter for guests who might otherwise be unaware.

These policies are ***not just about guns, murderers, drug dealing, other criminal activities or privacy ... it's about safety for the masses***. There are many more policies being set in place across the country and attendees at any IDA event can rest assured that we will review security policies of any property to ensure the safety of our guests and attendees. It is a shame our world has come to such a security based intensity to cope with this extreme level of insanity, but we need to remember ... If you make something idiot proof, someone will build a bigger idiot!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EDUCATION COURSE REVIEW

The Industrial Diamond Association of America (IDA) presented its Education Course, *Superabrasive Materials, Principles and Applications* this past November and once again, it was a tremendous success! There were nearly 60 attendees representing 39 companies and 5 countries.

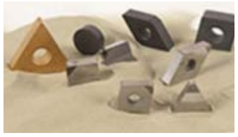
Excellent presentations and instructions were given by a knowledgeable and experienced group of instructors. This course showcased **DAVID SPELBRINK** of LANDS Superabrasives, **JOHN GUENTHER** of Radiac Abrasives, **ROB ROBBINS** of Rush Machinery, **JEFFREY BADGER, PhD** The Grinding Doc, **RADU COMAN, PhD** of GENENTECH, **MICHAEL HOBBS** of Blaser Swisslube, **SCOTT RIES** of ServeSix, **BILL SHAFFER** of Conicity, **ED FRANCIS** of Crystallume Engineered Diamond Products, **MIKE MacARTHUR** of Robbjack Corporation, **STEPHEN KELLY** of Element Six and **ABDELATIF ATARSIA, PhD** of YG-1 USA.

These instructors gave technical presentations and demonstrations on all aspects of machining and grinding including Superabrasive Grains, CVD Diamond and Polycrystalline Materials, Wheels, Bonds, Parameters, Truing & Dressing, Edge Prep, coolants/delivery and *Analysis of grinding tests*. Superabrasive Materials Principles and Applications was a ***TWO-DAY*** course wholly sponsored by the IDA and its membership and designed specifically to educate on the use of industrial diamond, cubic boron nitride (cBN), CVD Diamond & cBN, Nanodiamond and polycrystallines classified as superabrasives. The course was Non-commercial, unbiased and representative of accepted principles and practices in the industry. The course had ***classroom technical sessions complimented by laboratory demonstrations and class participation*** covering a wide range of products and applications of superabrasives for the automotive, aerospace, medical electronics, optics and other related industries using superabrasives. The course gave the attendees an education on superabrasive materials, principles and applications in the primary areas of grinding, machining with peripheral explanation for other uses, such as wear-resistant materials and non-abrasive applications.

This course educated a broad range of engineers, toolmakers, machine operators, suppliers, end users and other interested individuals that currently employ superabrasives in manufacturing operations on how they can optimize their use of superabrasives and perhaps expand their use into other areas and applications. This course also educated those that may be unfamiliar with superabrasives or currently using conventional abrasives so they understand the advantages of superabrasives and how they can be applied to increase productivity, reduce scrap and improve the cost effectiveness in manufacturing operations. The surveyed attendees overwhelmingly rated this course one of the best they had ever attended and gave exceptional marks *across the board* for all aspects of the course. If you were unable to attend this recent session, look for the next course in the summer of 2018!

NEWS &notes

SANDVIK HAS SIGNED AN AGREEMENT TO DIVEST HYPERION



Sandvik has signed an agreement to divest Hyperion to the US listed investment firm KKR at a price of 4 billion SEK. Hyperion delivers advanced wear-resistant tools, applications and components in hard and super-hard materials. Hyperion, with approximately 1,400 employees, has in the last twelve months reported revenues of 3.2 billion SEK, representing 4% of Sandvik's total revenues. "This agreement is an important step in focusing Sandvik on its core businesses. The divestment creates additional capacity for growth and expansion for the core business of Sandvik", says Björn Rosengren, President and CEO of Sandvik. For additional details visit: https://www.hyperion.sandvik.com

AEROSPACE SUPPLIER COLLABORATES WITH FIVES TO ADVANCE TITANIUM CUTTING

Acromil Corporation, a primary supplier of complex structural components and assemblies to the aerospace and defense industries, has ordered two advanced Cincinnati Wide-Range (WR) Titanium Profilers and a Giddings & Lewis Horizontal Boring Mill (HBM) from Fives as the start of a two-phase expansion. Acromil and Fives will also collaborate to establish a world-class hard metals manufacturing center with the latest 5-Axis high metal removal technology, with a goal of developing the most productive titanium cutting machines available. "Our expansion demonstrates a commitment to the defense and aerospace industries, with the primary goal of developing Acromil to be a Tier 1 supplier" said Ed Hatcher, Acromil's Executive Vice President. "We believe our collaboration with Fives Group will change the way aerospace manufacturers approach titanium machining." For additional information: http://metal-cutting-composites.fivesgroup.com.

LIEBER & SOLOW LTD., A LEADING SUPPLIER OF DIAMOND PRODUCTS IS PLEASED TO ANNOUNCE THE ADDITIONS OF MR. DAVID SPELBRINK AND MR. DAN ROFFMAN AS PARTNERS IN THE FIRM

As part of this restructure, Lieber & Solow has made some additional changes to the management team. Mr. Arnold Lieber is now the Chairman of the Board and Mr. Steve Roffman is now President. Mr. David Spelbrink and Mr. Daniel Roffman will serve as Vice Presidents to the firm. The new leadership team has a combined diamond experience of 125 years and ensures Lieber & Solow remains a leader in the industrial diamond field. Lieber & Solow, co. an industrial DGBSS Sightholder (and one of the oldest remaining DeBeers' Sightholders) specializes in natural industrial diamonds for dressing, drilling, cutting and wear applications – while the LANDS Superabrasives division produces, micronizes, assorts, crushes, coats and treats a full range of natural and synthetic diamond and CBN powders and grits. With David's extensive background within the company he will continue to work in the day-to-day operations of LANDS Superabrasives but with his new role, he will play an integral role in the Lieber & Solow natural diamond side. Daniel's focus has been on the natural diamond stones with his extensive travels for supply at both the DBGSS sights and within the market as well as interaction with customers. His experience and expertise will now also be parlayed into the LANDS business side.

NEW LAW BOOSTS BOEING'S COMPETITIVENESS, SUPPORTS LONG-TERM GROWTH BOEING ANNOUNCES IMMEDIATE ADDITIONAL EMPLOYEE-RELATED AND CHARITABLE INVESTMENTS OF $300 MILLION

Chairman, President and Chief Executive Officer Dennis Muilenburg praised the tax bill passed by Congress as a critical driver of business, economic growth and innovation for the United States and for Boeing. "On behalf of all of our stakeholders, we applaud and thank Congress and the administration for their leadership in seizing this opportunity to unleash economic energy in the United States," said Muilenburg. "It's the single-most important thing we can do to drive innovation, support quality jobs and accelerate capital investment in our country." Muilenburg announced immediate commitments for an additional $300 million in investments. "Each of these investments benefits Boeing's most important strength – our employees – and reflects the real-time impact and economic benefit of the reforms," said Muilenburg. For more information visit: http://boeing.mediaroom.com/index.php?s=20295&item=130098

Calendar *of* EVENTS

To have your event or conference listed, please send information to: Finer Points Event Calendar • P.O. Box 29460, Columbus OH 43229 • Fax 614-797-2264 or email: tkane-ida@insight.rr.com

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MD&M WEST

FEBRUARY 6-8, 2018
MD&M West 2018
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mdmwest.com
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METAV 2018
DÜSSELDORF, 20 - 24 FEBRUARY
POWER YOUR BUSINESS
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FEBRUARY 20-24, 2018
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Messeplatz
Düsseldorf, Germany
49 0 211 4560 01
metav.com

THE MFG MEETING

MARCH 7-10, 2018
The MFG Meeting 2018
MFG Meeting by AMT--The Association For Manufacturing Technology and National Tooling & Machining Association (NTMA)
themfgmeeting.com
Trump National Doral Miami, Florida
trumphotels.com

csda

MARCH 8-10, 2018
The 46th Annual Convention & Tech Fair of the Concrete Sawing & Drilling Association
Grand Wailea - A Waldorf Astoria Resort
Wailea, Hawaii USA
www.csda.org/convention
info@csda.org • 727-577-5004

AERODEF MANUFACTURING

MARCH 26-29, 2018
AeroDef 2018
aerodefevent.com/
Long Beach Convention Center
Long Beach, CA United States

MACH 2018

APRIL 09-13, 2018
Manufacturing Technologies Association (MTA)
machexhibition.com
NEC Birmingham
Birmingham, United Kingdom
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APRIL 9-11, 2018
Industrial Diamond Association of America Biennial Meeting *in* Conjunction with UAMA Spring Meeting
The Naples Beach Hotel & Golf Club
Naple, Florida

OFFSHORE TECHNOLOGY CONFERENCE OTC

APRIL 30 to MAY 3, 2018
Offshore Technology Conference (OTC)
Houston, Texas, USA
NRG Park
http://www.otcnet.org/

AM2018
Additive Manufacturing Conference

MAY 9, 2018
3D Printing Workshop @ NPE2018
Additive Manufacturing
additiveconference.com
Orange County Convention Center
Orlando, FL

WAI OPERATIONS SUMMIT WIRE EXPO

MAY 14-16, 2018
WAI Operations Summit & Wire Expo
Gaylord Opryland Resort & Convention Center
Nashville, Tennessee, United States
www.wirenet.org/events/20-wai-article/178-wai-operations-summit-wire-expo
1-203-453-2777

NDNC 2018
12th New Diamond and Nano Carbons Conference

MAY 20-24, 2018
New Diamond and Nano Carbons Conference
Flagstaff, Arizona
http://www.mrs.org/ndnc-2018

2019

MAY 29, 30 & 31, 2019

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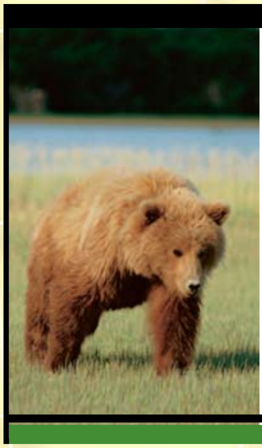

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But what about tomorrow? While hundreds of millions of Americans are enjoying the wonders of our national parks each year, the future of the very things they're coming to see is at risk. For example, although the Mexican black bear population has been slowly recovering at Big Bend National Park, their ongoing survival is threatened. Americans for National Parks is a coalition working to preserve these national treasures, and all the priceless experiences they provide. Find out how you can help at: **www.americansfornationalparks.org**.

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PCD Bits for UNDERGROUND ROOF BOLTING

L.F. GARCIA, Ph.D.
Sandvik Mining and Construction G.m.b.H • Zeltweg, Austria

ABSTRACT

This work first describes briefly some of the roof bolting technologies available in the market for soft and hard rock conditions. For targeting particularly roof bolting in coal mines, Sandvik has developed a new PCD drill bit line giving an increase in performance productivity for Sandvik continuous bolter miners. Experimental work during product development was mainly carried out by laboratory drilling with one instrumented Sandvik DO100 drill-rig and incremental improvements were observed by analyzing drilling parameters data logs, bit failure mechanisms and estimated total bit lifetime. PCD characteristics including different finishing conditions were tested and analyzed. A final design was qualified at the laboratory and confirmation with mine field tests collected. Tests beyond the original target are highlighted including hard-rock granite drill experiments with an adapted Sandvik Axera 5 at Sandvik´s Tampere test mine in Finland.

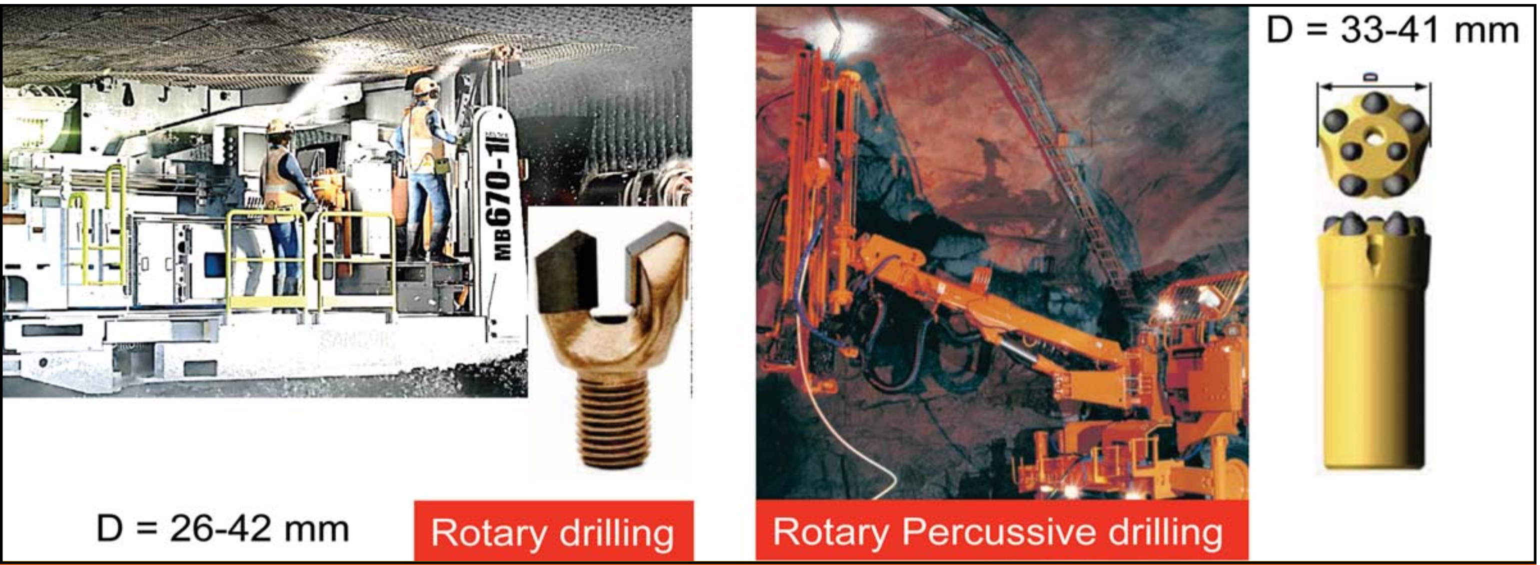

FIGURE 1: Examples of the automation level and tools used for soft rock drilling with carbide rotary bits (a) and hard rock drilling (b) with carbide percussion bits.

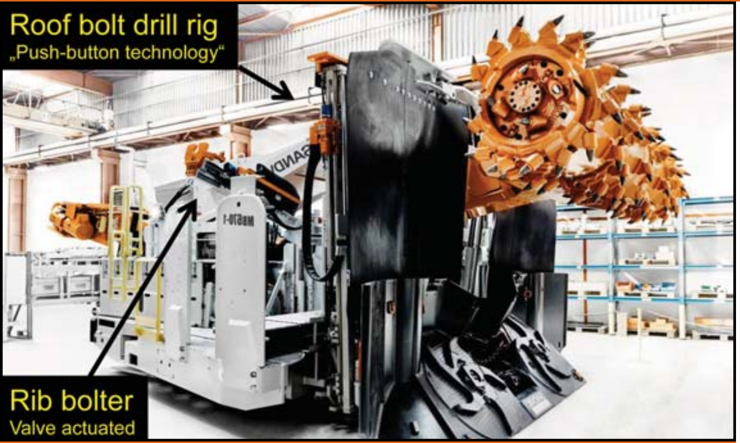

FIGURE 2: A Sandvik MB670 continuous bolter miner showing roof and rib bolt rigs.

INTRODUCTION

Roof bits are used to drill holes in the strata before anchoring bolts are utilized to secure the roof of mines. The first application of diamond for roof bits dates to more than 20 years ago. Originally those bits were targeted for North American coal mines trying to replace traditional carbide bits. The main objective for using PCD was to extend the life of the tools and simplify the logistics of the operations by reducing the number of bit-changes per time period. The perceived reliability of operation by the customers has been the main problem for extending the usage of these drill bits.

DRILLING FOR ROOF BOLTING

Two types of roof bolting technologies exist primarily based on the rock type to be drilled. For hard rock mines like copper or platinum mines, roof rock drilling with percussion bits has shown to be the most economical choice. For more soft rocks like coal or potash/salt mines pure rotary drilling is used since higher drilling speeds are theoretically achievable. The drilling equipment and consumable tools are more economical for the case of pure rotary action and they are normally preferred when the rock conditions allow their use. Percussion drilling is accomplished by using small diameter top-hammer bits. In this case, carbide inserts are fixed to a steel body following some distribution pattern Figure 1(b). The cutting action is performed by the crushing of rock by the buttons during the percussion action and subsequent removal of chips during tool rotation. Even though the optimization of this type of drilling takes into account the intricate relationship between the percussion frequency and rotation speed (rpms), the drilling action can reach high levels of energetic efficiency in hard rock. A "hard rock" condition is being considered generally by Sandvik in underground mines when the compression strength of the rock is larger than 100 MPa in UCS (unconfined compression strength) along with some other parameters that define the rock mass situation. To the best of the author´s knowledge, there is no current PCD top-hammer tool being offered in the market for this application. The reason for this may be related to reliability and cost per hole issues. For the case of pure rotary drilling, the necessary equipment and associated electronics are less complex and easier to maintain than a percussion unit. Additionally the size of the equipment and accessories are smaller and the hydraulic system has less requirements. The parameters that can be governed in a pure rotary system for the drilling application are the thrust force, the torque and the rotation speed (rpms). Normally all three can be controlled independently from each other in a hydraulic system. Bits for pure rotary drilling have the characteristic that they cut the rock by a process of indentation and subsequent removal of the cuttings by the torque action. No impact is transmitted to the cutting material as in the case of percussion drilling. The typical shape of pure rotary drilling tools is as in Figure 1(a). A chisel shape cutter is the most common geometry as it is very efficient in indenting the rock. Carbide with relatively high strength and toughness has been the material of choice for these tools. Again the high cost associated to the PCD material has been responsible for the difficulty in the introduction of diamond tools into this market sector. A high degree of reliability is required for the successful acceptance of the customers to implement PCD materials.

PCD BIT DEVELOPMENT AT SANDVIK

The starting point of the development of PCD bits was an original design developed by Sandvik drill bit development team. The work was mainly driven by a strong CAD/CAM system to model the main bits characteristics like cutting angles, flushing design and cutter shape. Two additional milestones speeded up the development process in recent years: a braze laboratory for quick prototype manufacturing was established together with an instrumented drilling laboratory. The braze laboratory made it possible to optimize the braze joint by selecting braze material and process. One major goal was to develop a process where the steel bit body heat treatment would withstand the application. The drilling laboratory enabled the possibility to study experimentally the influence of cutting angles and flushing design. From the cutting angles point of view, the back rake angle and side rake angle are the most important factors influencing the resultant acting cutting force, normal force and side force on the bit. Those force components are integrated to deliver the required motor torque and cylinder feed force to cut the rock.

LABORATORY DRILLING

The drilling laboratory established at Sandvik Zeltweg location is utilizing a Sandvik DO100 drill rig type. This drill rig is commonly used in Sandvik continuous bolter miners. Bolter miners have usually 4 drill rigs of this type for roof bolting and 2 additional drill rigs for side bolting, called 'rib bolting' Figure 2. The DO100 is equipped with an electronic unit for the control, monitoring and semi-automation of the drilling process. Feed forces of about 10 to 25 kN are standard, a rotation speed (rpms) of about 700 rpms is possible depending on the oil flow rate set and torque of about 135 Nm max is available at the spindle. In the bolting mode, the torque can reach up to 267 Nm at 300 rpms. The rib bolters are normally valve actuated and require full manual operation. The DO100 was placed under a steel structure onto which rock or concrete blocks are positioned to be used as base materials Figure 3. A first step before any drilling process starts is to characterize the base material to be drilled. A rock analysis laboratory is operating at Sandvik Zeltweg location where main rocks characteristics like UCS, BTS (Brazilian tensile test) and the Cerchar Abrasivity Index (CAI) can be determined for any rock. By analyzing the target mine rock data, a concrete or similar rock can be selected to qualify the drilling process. The DO100 drill rig is additionally instrumented with pressure sensors in the motor and feed cylinder. In this way and by knowing the cylinder internal geometry and equations for the hydraulic motor it is possible to calculate torque, feed force, rpms and feed speed (drilling speed). What is particular for every rig is the way the system controls all these 4 variables during the drilling operation. In the case of the DO100 and for most underground drill rigs, the feed speed is setup by the operator in the control unit. The rotation speed (rpms) has a fixed value adjusted by the oil flow to the motor. The torque and feed force are adjusted by the electronic system to cope with the given feed speed selected. This type of control has proven to be the best option for giving a reliable and robust system and gives the operator the ability to control the most important parameter in the underground operation, the feed speed.

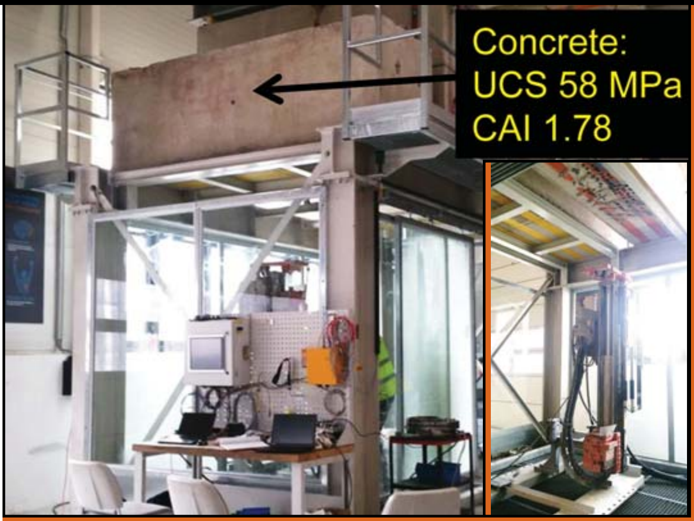

FIGURE 3: Layout of the drill rig laboratory at Sandvik Zeltweg site.

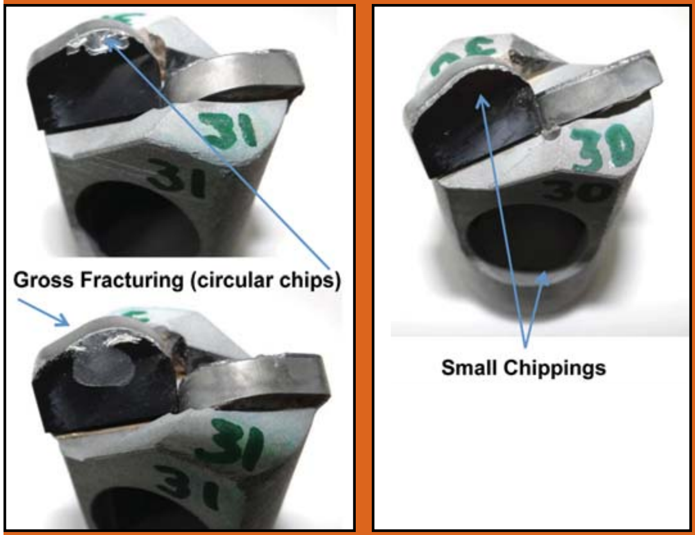

FIGURE 4: Influence of back rake angle on the chipping type observed in drill bits. Bits with -20° rake angle show large gross fracturing areas whereas bits with -30° rake only small clippings along the cutting edge.

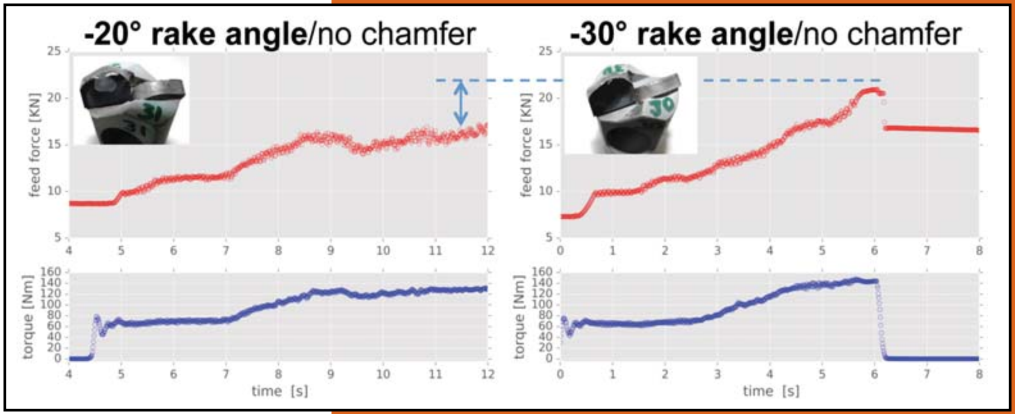

FIGURE 5: The -30° rake angle bit shows 15 to 25% higher feed force requirements than the -20° rake angle to drill at same speed.

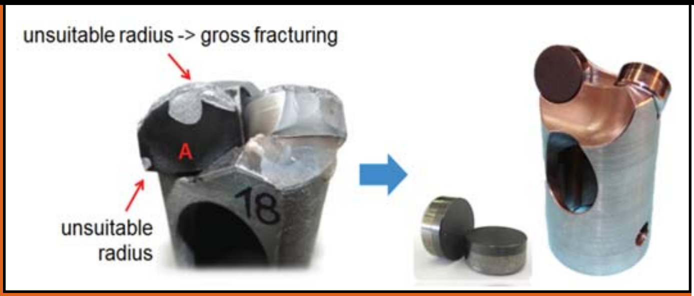

FIGURE 6: Redesign of bit utilizing standard single-pressed cutters.

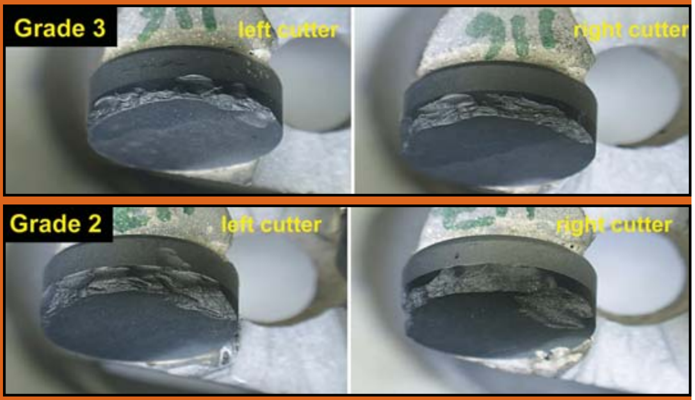

FIGURE 7: Comparison of initial chipping characteristics of Grade 2 and Grade 3 PCD bits.

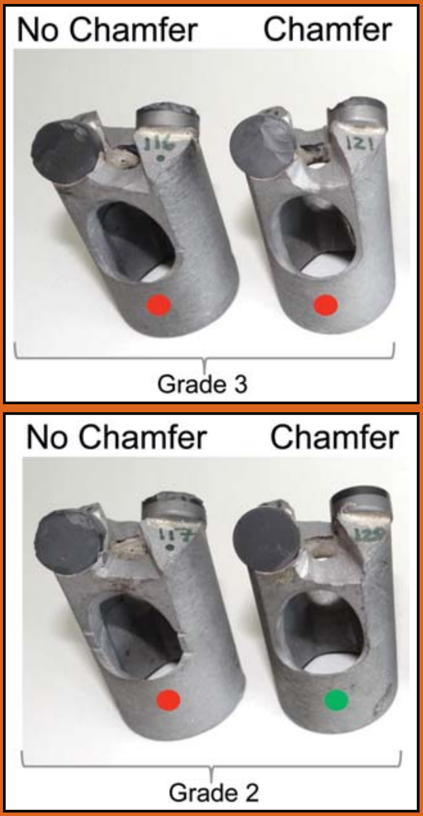

FIGURE 8: Selection of PCD grade and chamfer after experimental drilling in concrete for 6 meters. Only PCD Grade 2 with chamfer was able to survive without failure.

TESTING OF BITS WITH DIFFERENT BACK RAKE ANGLES

The influence of the back rake angle on the cutting efficiency (specific energy) is well documented in the literature. Back rake angle is being selected based on the target rock and depth of cut to be encountered. What is less documented is the influence of back rake on the chipping type- and extension observed in PCD cutters. In this work, two back rake angles were tested -20° and -30°. First used cutters were initially EDM cut from a 60 mm PCD blank. The coarse PCD grade contained 20 to 30 microns diamond particle size and very low binder content giving an extra strong PCD grade. This PCD grade was designated as Grade 1 and it was considered the strongest grade tested during the project. Bits were tested at the laboratory using both rake angles and after 4 meters of cumulated drilling; the visual aspect of the tools was as given in Figure 4. It could be seen that the -20° back rake presented a circular chip on the PCD face of one cutter and a macro cutter fracture on the second one. In contrary the bit with -30° back rake presented only small chippings, but along the whole cutting edge in both cutters. This experiment made possible to detect the 'transition back rake angle' between macro chipping and micro chipping experimentally for the PCD Grade 1. Macro chipping (gross fracturing) and micro chipping classification is being considered as in reference. In general it is accepted that a lower rake angle (-20° in our case) makes the bit more aggressive but as a negative consequence gross fracturing of cutter starts to be more frequently observed. On the other hand, an aggressive situation is desirable in terms or rock cutting mechanics since by considering all other parameters equal, the drilling speed will be higher. The difference between both rake angles is more evident by looking at the response of the drilling parameters with these two versions. An experiment was set up to drill with both bits at extreme conditions in concrete. As a safety feature, whenever the pressure in the hydraulic system (in the cylinder or in the motor) reaches 200 bar of operation the drill rig will automatically stop by the action of pressure release valves. By drilling under extreme conditions (situation that can take place in mines when seams of rocks intercalate between the main rock) it could be observed in the laboratory that the 200 bars level was reached in both cases at the motor inlet, reaching the maximum 137 Nm of operation. Under those conditions the normal force required to drill with -20° rake was 15 to 25% lower than that of the -30° (Figure 5). The efficiency of the -20° rake was validated but on the other hand the appearance of macro chipping was also evident for that selected angle as mentioned previously.

FINAL BIT SPECIFICATION

At this point of the technical development, the focus was set on eliminating the chipping of the cutters. Therefore, in order to mitigate the cutter fracture phenomena and be able to utilize the -20° rake angle, 3 major factors were studied: Cutter shape design, PCD grade material and Chamfering and finishing. By extending the integrity of the cutting edge, the reliability and total lifetime of bits would be increased. Additionally, the ability to use lower rake angles would enable to develop a faster bit.

PCD CUTTER SHAPE

A change to a more common and simpler geometry was pursued (Figure 6). Many reasons favor this decision: standard cutter sizes are available, no extra EDM is necessary, optimization of internal stresses situation possible, ease of chamfering and extensive PCD grades available. Cutters of 12 and 13 mm diameter were used for building drill bits of 25.4 mm diameter. For a bit of 35 mm, cutters of 16 mm diameter had to be selected in order to avoid the appearance of a "large" rock core between the cutters while drilling. Whenever an internal rock core is generated, the drilling speed will be reduced if the rock core does not break or cannot be removed easily.

PCD GRADE SELECTION

PCD Grade 1 was considered as too strong for the application and softer grades (with less wear resistance and lower rupture strength) were used for further trials. Two new grades (Grade 2 and Grade 3) were selected for the final specification design. Both had a coarse grain structure of 20 to 40 microns of diamond particle size but had different binder fraction content. The two new grades complemented the first selected one in the following way: Grade 1 = 'extra-strong

PCD', with low binder content, Grade 2 = 'strong PCD', with low binder content and Grade 3 = 'tough PCD', with higher metal binder content. The Grade 2 had theoretically larger rupture strength than the high-binder PCD Grade 3. Both cutters types were initially tested without chamfering by drilling concrete. Pictures can be seen on Figure 7. Grade 3 showed a tendency to produce smaller chippings (probably transgranular in fracture). Grade 2 showed larger micro chippings and presenting probably a more intergranular fracture type. For both grades the bonding between PCD-table and carbide was considered as highly satisfactory due to the fact that some chippings were not stopping at the interface but took part of the PCD-table and the carbide substrate.

CHAMFERING AND PCD GRADE

The use of chamfering to extend the durability of PCD cutters has been long recognized in the industry and has been extensively summarized recently. In order to completely eliminate chipping it was necessary to build a proper chamfer along the cutting edge of the cutters. After different trials a constant thickness of 0.2 mm at 45° was tested in both grades. Drill tests were performed and the results can be seen in Figure 8. For Grade 2 the tested chamfer (0.2 mm / 45°) proved to be effective in eliminating chipping. Same chamfering was not effective in the case of Grade 3. The reason for this difference may be related to the higher rupture strength of Grade 2 compared to Grade 3.

LABORATORY VALIDATION AND MINE TESTING

Following the selection of the cutter shape, PCD grade and chamfer design, a series of pre-serial tests followed at the laboratory. Those tests proved to deliver a satisfactory drill bit. After some CAD modifications to the steel body, field testing in a coal mine was performed delivering successful results (Figure 9). In general PCD bits delivered around 100 to 200 times more holes than comparable carbide bits. The value proposition of the bits were validated in terms

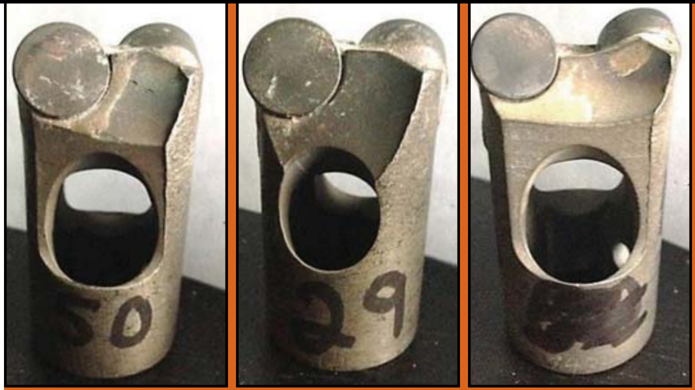

FIGURE 9: Validation of field tested pieces with 50, 29 and 27 drilled holes (2 meters each).

ACKNOWLEDGEMENTS

The author wants to first thank Sandvik AB for the permission to publish this work on the development of PDC bits for roof bolting. Special thanks to Edgar Halling of Sandvik Mining and Rock Technology for encouraging the preparation of this paper and to Weston Doley for reviewing the content. The following Sandvik AB colleagues collaborated with this work in different phases of the project: Roland Hölzl, Harald Paulin, Manoj Kumar, Harald Wurmbauer and Hannes Voitic. For tests performed at the Tampere mine many thanks to Annukka Kokkonen and Jarmo Poutanen. The technical support and material provided by MegaDiamond, a Schlumberger Company, along this project is very much appreciated.

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HARD ROCK TRIALS

Sandvik operates a test mine at its Tampere location in Finland. This mine is used to test new technologies in both, machines and consumables. Tests were performed at this mine by adapting one Sandvik Axera 5 which is normally operating top-hammer bits. A pure rotary system was mounted on one boom and hard rock drilling with PCD bits was performed. The abrasivity of the mine's rock was around 5 to 6 CAI units; an abrasivity much larger compared to the target mines in North America (showing 2 to 3 CAI). The first bits were able to drill properly in granite and reached 27 meters of lifetime (Figure 10). Comparable carbide bits were delivering less than 1 meter and showed always catastrophic failure as the end of lifetime. The speed of PCD rotary was between 0.1 to 0.5 m/min and remained not comparable to the 1.5 to 3 m/min than can be achieved by using top-hammer bits with percussion drilling.

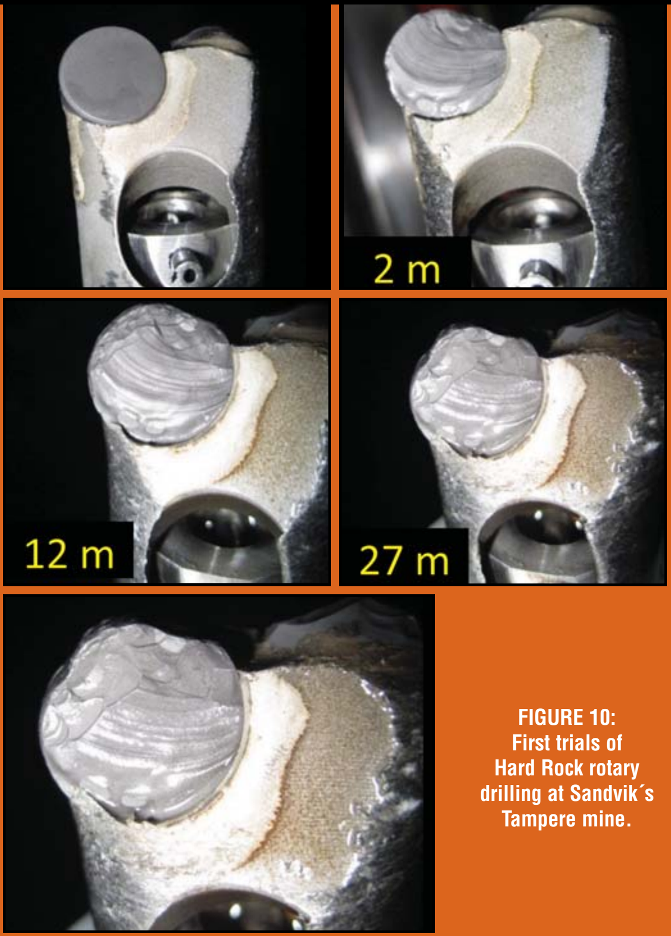

FIGURE 10: First trials of Hard Rock rotary drilling at Sandvik´s Tampere mine.

CONCLUSIONS

The following conclusions can be summarized based on this work:

- PCD cutters can be successfully used in roof bolting applications
- PCD chipping type (gross fracturing/chipping) is influenced largely by the back rake angle selection
- Transition between gross fracturing and chipping was determined experimentally to be between -20° and -30° rake angle for PCD Grade 1
- Tough and Strong PCD grades (Grade 3 and Grade 2) presented different chipping characteristics (fraction of intergranular/transgranular fractures) when no chamfer was used
- Chamfering effectiveness was dependent on the PCD grade strength
- Successful drill bit was an optimization of bit design, PCD grade selection and proper chamfering
- PCD pure rotary drilling was possible in hard rock granite. Target lifetime and speed remained lower compared to standard top-hammer bits with carbide inserts. ■

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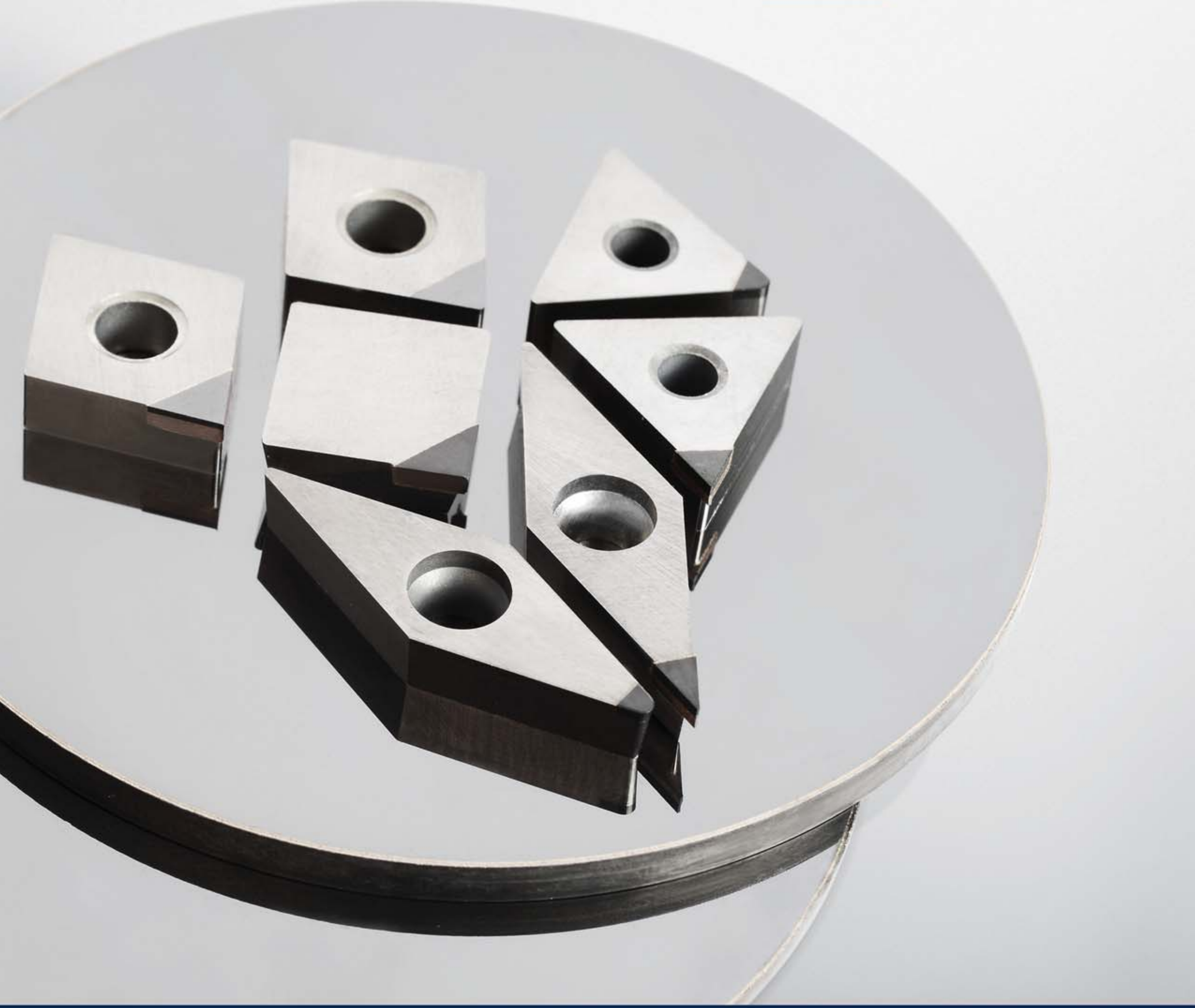

3D measurement	✓	C-scan	✓	Digital Microscope	✓	FE-SEM with EDX	✓	EOV CAM	✓

Measurement of Residual Stress of Polycrystalline Diamond Cutter (PDC) by X-ray Diffraction Technique

D.K. MUKHOPADHYAY and K.E. BERTAGNOLLI
US Synthetic Corporation, Utah USA

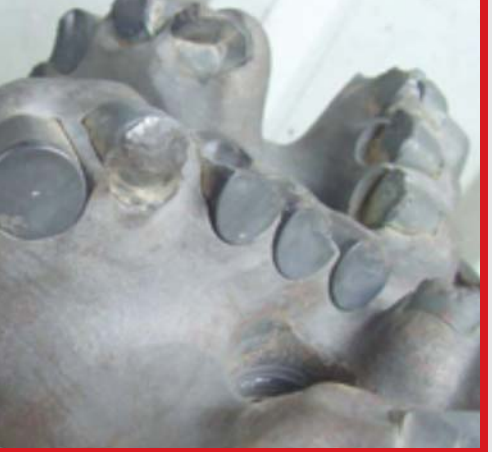

Figure 1: Typical PDC failure mode experienced in hard rock drilling.

Since their introduction over 30 years ago, polycrystalline diamond cutters (PDC) have made a significant impact on the oil and gas drilling industry.

Abstract

An attempt had been made to measure the residual stress of Polycrystalline Diamond Cutter (PDC) by X-ray diffraction (XRD) method. Residual stress is the stress that a PDC retains after sintering. The residual stress in a PDC plays an important role for cutter performance. X-ray diffraction method of residual stress measurement is attractive because it is nondestructive. Residual stress in a material changes its lattice spacing and XRD technique measures the change of lattice spacing to calculate the magnitude of stress. A powder diffractometer was used for residual stress measurement. (311) diamond peak at a two-theta value of 91.5 degree was used for the measurement. Sin^{2} Ψ method was used where Ψ is the tilt angle. Stress measurement was done at the center of top surface of the cutter with X-ray beam of size 3 mm x 1mm. Stress values were compared between PDC samples sintered under different HTHP (high temperature high pressure) conditions. Effect of diamond table thickness on residual stress values was also studied.

Introduction

Since their introduction over 30 years ago, polycrystalline diamond cutters (PDC) have made a significant impact on the oil and gas drilling industry. High penetration rate and long life are some of the attributes of PDC bits. However, PDC cutters may fail prematurely during hard rock drilling. Fig 1. shows a typical PDC failure mode which may be attributed to residual stress.

Conventional PDC inserts are made by sintering diamond powder on a cobalt-cemented tungsten carbide (WC-Co) substrate under high pressure-high temperature (HPHT) conditions around 6 GPa and 1400°C. During sintering, cobalt from the substrate melts and infiltrates through the pores among the diamond crystals, producing a zone of depleted cobalt in the substrate near theinterface. The molten cobalt dissolves carbon atoms from the diamond crystals and quickly saturates. The dissolved carbon precipitates and forms diamond-diamond bonding among thediamond crystals. As the pressure is released and the PDC cools from sintering, the diamond layer and the carbide substrate shrink at different rates, thus giving rise to residual stress in thePDC.

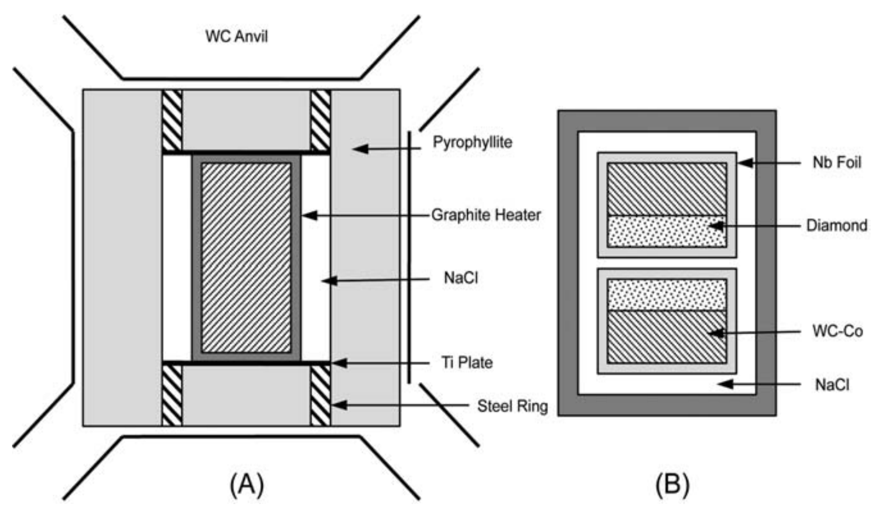

Figure 2: Sample assembly for high pressure-high temperature (HPHT) sintering of diamond. (A) Overall view; (B) enlarged view of graphite heater.

There are several techniques to measure residual stress in PDC. Diffraction methods include X-ray diffraction (XRD), neutron diffraction, synchrotron X-ray, and Raman scattering. Diffractiontechniques are generally non-destructive methods of residual stress measurement in PDC. Both neutron and synchrotron techniques have high penetration depth in comparison to X-raydiffraction or Raman but they need special facilities. Shallow penetration depth of XRD technique allows measurement of stress on the surface in the cutting areas of the PDC. Relaxationmeasurement methods include hole drilling, ring coring, slitting, and grinding. Relaxation methods are destructive and often difficult given the super hard material properties of PDC.

Experimental Procedure

High pressure sintering was carried out using a cubic-type HPHT apparatus. Temperature was measured with a

W5%Re-W26%Re thermocouple without correction for the pressure effect.Pressure was calibrated at room temperature using the known transitions of Bi, Tl, and PbTe. Diamond powder (30 µm grain size) and a WC-Co substrate (13 wt.% Co, 2–4 µm WC grain size) were enclosed in a niobium capsule, surrounded by sodium chloride, placed inside a graphite resistance heater, and enclosed in a pyrophyllite cube as shown in Fig. 2. The samples were first subjected to a pressure of either 6 or 8 GPa. The temperature was then raised to approximately 1400 °C by passing electric current through the heater. The sample was maintained at temperature for approximately 2 minutes. Power was then turned off and the cell was cooled before pressure was released. Typical run times were on the order of 6 minutes. Once sintered, the samples were removed from the cube assembly, and the diamond table was lapped flat. The parts were then ground to a diameter of 15.9 mm and an overall height of 13.2 mm. A summary of the experimental conditions for the samples measured in this study are listed in Table 1.

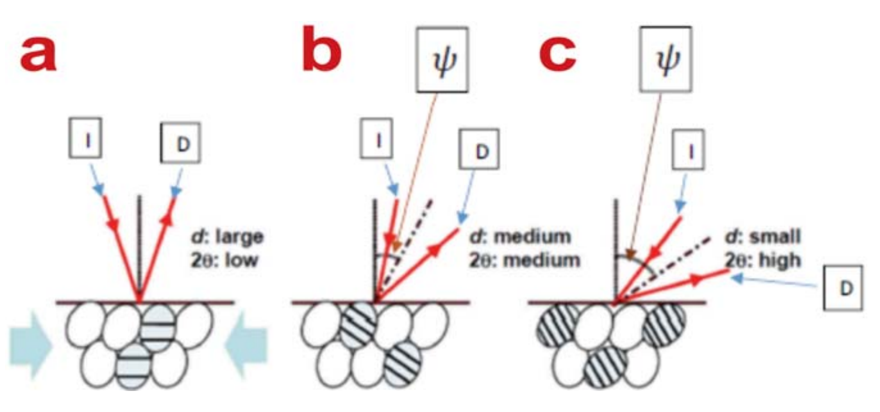

Figure 3: (a) Incidence and (b) Diffraction of (c) X-ray Beam at Three Different Ψ Angles

Table 1: Experimental Conditions

Sample	Sintering Pressure (GPa)	Diamond Table Thickness (mm)	Diameter of PDC (mm)
1	8	2.1	16
2	6	2.1	16
3	6	2.1	16
4	6	3.2	16

A Rigaku Ultima IV powder diffractometer was used for the XRD residual stress measurements. Copper $K\alpha$ beam was used. The (311) diamond peak at a two-theta value of 91.5 degree was used for the measurement. Sin$^2\Psi$ method was used where Ψ is the tilt angle. Stress measurement was done at the center of top surface of the cutter with X-ray spot size 3 mm x 1 mm.

The strain gage measurements were made by bonding a rosette strain gage (Micro Measurements model WA-06-030WR-120) to the center of the diamond table surface. The strain gage was zeroed, and then strain values were measured as the substrate was ground away. The diamond table is assumed to be stress-free when all the substrate material has been removed. The stress-free strain measurement is then subtracted from all other strain values, and the first principal stress is calculated from linear elastic theory.

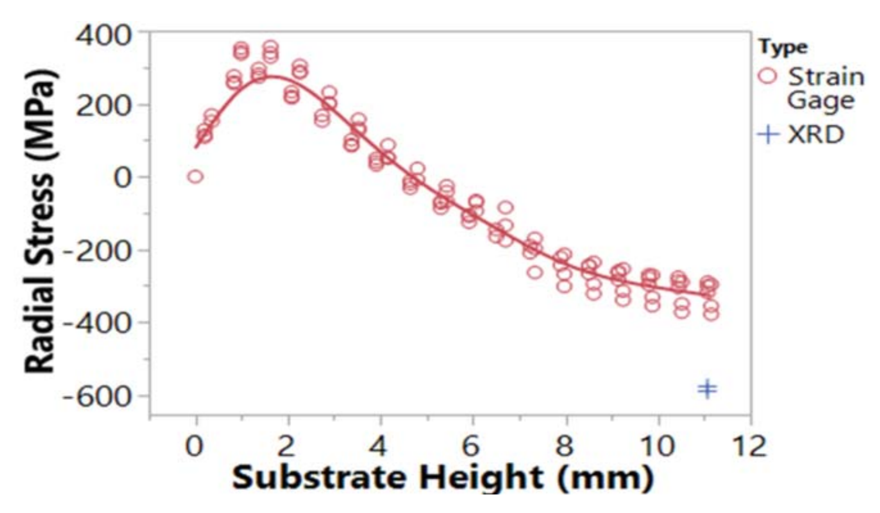

Figure 4: Comparison of XRD and strain gage residual stress measurements for Sample 2 and Sample 3.

Results and Discussion

A crystalline material is defined as a solid that consists of definite periodic arrangement of atoms in three dimensions. These planes of atoms can create constructive or destructive interference of X-ray beam and diffraction of an X-ray beam happens by constructive interference when the beam obeys Bragg's law, which is, λ = 2d Sin Θ, where λ = X-ray wavelength, d = interatomic spacing, and Θ = diffraction angle. If the residual stress is present in the sample, then the interatomic spacing (d) will be different than in an unstressed state. If the lattice is under under compression the interatomic spacing (d) will be smaller and the peak

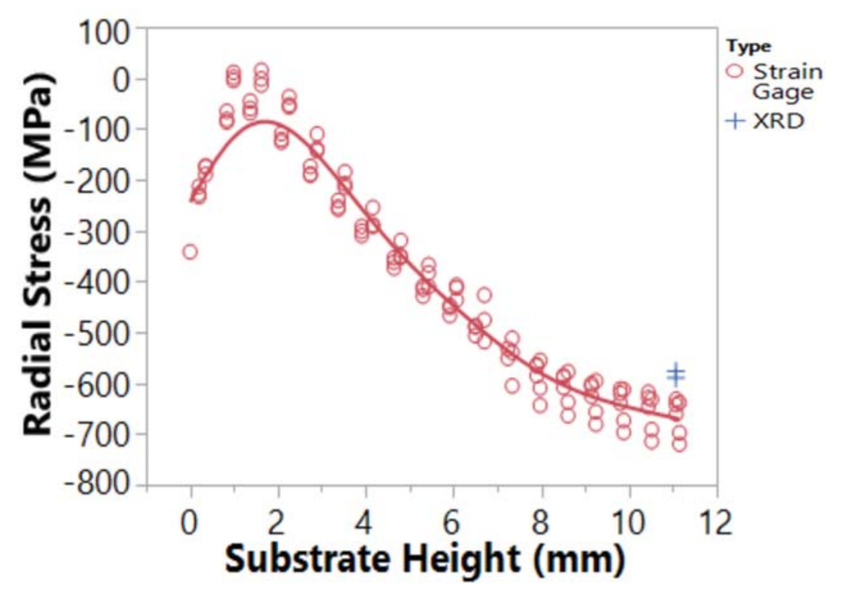

Figure 5: Adjusted strain gage values compared to XRD measurements of Sample 2 and Sample 3.

will shift to higher angles according to Bragg's law.

Fig 3. shows that angle Ψ is the angle between the diffraction plane normal and the bisector of the incident and diffracted beams. Fig 3 (a) also shows that at Ψ = 0° the diffraction plane normal and the surface normal and the bisector of incidinet and diffracted beams are the same.

Figure 3 (a) shows that that the diffracting lattice planes are parallel to the surface and hence the compressive stress shown would not affect this lattice spacing. In Fig 3 (b) and Fig 3 (c) the sample is rotated at two different Ψ angle. The orientation (b) and (c) show changes in lattice spacing due to the presence of stress. This change in the lattice spacing can be measured from the peak shift. Thus, the lattice spacing acts as a strain gauge in this XRD stress measurement technique. The equation for stress calculation using XRD is,

$$\sigma = \frac{E}{(1+\nu)\ \mathrm{Sin}^2\Psi}\ \frac{(d_n - d_o)}{d_o}$$

where:

σ = Residual Stress
Ψ = Tilt Angle
ν = Poisson's Ratio
E = Young's Modulus
d_n = Inter-planar Spacing Measured at Each Tilt Angle
d_o = Initial Inter-planar Spacing

From the above equation, we can measure the change in lattice spacing from the peak shift. In our present experiment (311) diamond peak at 91.5° was chosen due its relatively higher intensity and high angle position. High angle peak is chosen because the error in Sin Θ for a given error in Θ decreases as the value of Θ increases [6]. The diffraction data was collected at three psi angles. The Young's modulus (E) of the diamond table used in this calculation is 850,000 MPa. The Poisson's ratio (ν) used is 0.2. Three diffferent Ψ angles (0°, 24.9° and 36°) were used for stress measurement in the present experiment. Table 2 showed measured residual stress values by XRD.

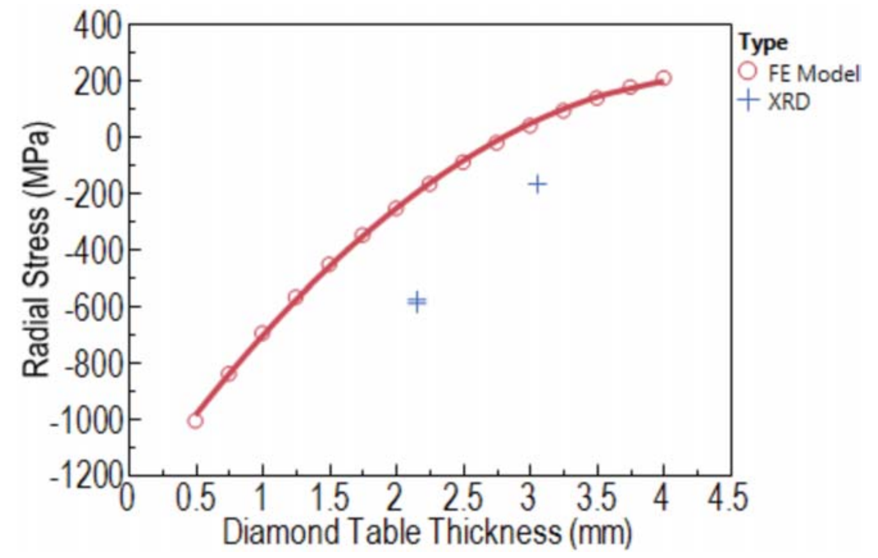

Figure 6: Effect of diamond table height on residual stress (Samples 2, 3 and 4).

Table 2 shows the measured residual stress values at different HTHP conditions. Data showed that 6 GPa sample has higher compressive stress than 8 GPa sample for same diamond table height. Data also showed that the residual stress decreased with increase in the diamond table height for same HTHP condition.

A comparison of the XRD residual stress measurements with strain gage measurements for Sample 2 and Sample 3 is shown in Fig. 4. Both the XRD and strain gage measurements show the diamond surface is in compression when attached to the full substrate. As the substrate is removed, the diamond begins to expand outward, relieving some of this compression. In addition, the relatively stiff carbide support is being removed, allowing the diamond surface to bend slightly. Eventually enough carbide is removed to allow a significant amount of bending of the diamond surface, putting the diamond surface into tension. When

Table 2: Measured Residual Stress Values by XRD

Sample	Sintering Pressure (GPa)	Diamond Table Thickness (mm)	Diameter of PDC (mm)	Stress (MPa)
1	8	2.1	16	-428
2	6	2.1	16	-575
3	6	2.1	16	-588
4	6	3.2	16	-166

the substrate is completely removed, the diamond table can expand fully, and the diamond surface is assumed to be stress free.

Clearly the XRD technique is measuring higher compressive stress than the strain gage. We believe this is because the diamond table is not truly stress free when the substrate is removed. The interstitial cobalt in the diamond table tends to pull the diamond into compression even in the absence of the substrate. To test this hypothesis, we measured the diameter change of the diamond table before and after removal of the cobalt phase by acid leaching. The diameter changed an average of 0.0051 mm (.0042-.0060, 95%, n=18). This indicates that the diamond table is in compression when the substrate is completely removed. A compressive strain of 0.032% will produce a diameter change equal to 0.0051 mm. This strain value was subtracted from the strain gage measurements in Fig. 4, and the adjusted values are shown in Fig. 5. The good agreement between XRD measurements and the adjusted strain gage measurements supports our hypothesis that the diamond disc is not stress free when the substrate is removed. In fact, the diamond disc appears to be in compression when the substrate is completely removed.

Preliminary study of the effect of diamond table height on the residual stress of the PDC was done by XRD and is shown in Fig. 6. The graph showed that the residual stress decreased with increase in the diamond table height, matching the trend predicted by finite element analysis. ■

Conclusions

The XRD technique presented in this study provides for a nondestructive analysis of residual stress in PDC cutters. In this study stress values were compared between PDC samples sintered under different HTHP (high temperature high pressure) conditions. Study also showed that a thicker diamond table has less compressive stress than their thinner counterpart. Ongoing experimentation will focus on measurement system analysis (MSA) of stress measurement to understand the repeatability of the data.

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Spring 2018	Machining and Education	Mar. 1, 2018
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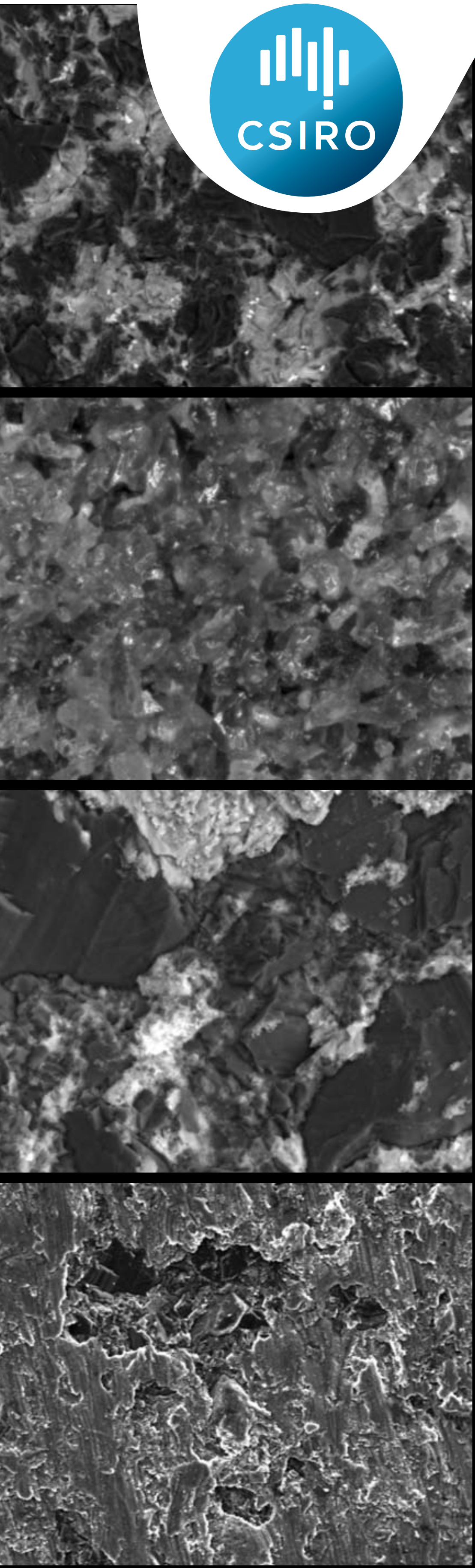
New Orleans has many visitor attractions, from the world-renowned French Quarter; to St. Charles Avenue, (home of Tulane and Loyola Universities, the historic Pontchartrain Hotel, and many 19th-century mansions); to Magazine Street, with its boutique stores and antique shops. According to current travel guides, New Orleans is one of the top ten most-visited cities in the United States. A recent poll of "America's Favorite Cities" ranked New Orleans first in ten categories, the most first-place rankings of the 30 cities included. According to the poll, New Orleans is the best U.S. city as a destination and for stylish boutique hotels, cocktail hours, singles/bar scenes, live music/concerts and bands, antique and vintage shops, cafés/coffee bars, neighborhood restaurants, and people watching. The city also ranked second for friendliness, hotels/inns, and ethnic food. The French Quarter (known locally as "the Quarter" or Vieux Carré), which was the colonial-era city and is bounded by the Mississippi River, Rampart Street, Canal Street, and Esplanade Avenue, contains many popular hotels, bars, and nightclubs. Notable tourist attractions in the Quarter include Bourbon Street, Jackson Square, St. Louis Cathedral, the French Market (including Café du Monde, famous for café au lait and beignets), and Preservation Hall. Also in the French Quarter is the old New Orleans Mint, a former branch of the United States Mint which now operates as a museum, and The Historic New Orleans Collection, a museum and research center housing art and artifacts relating to the history of New Orleans and the Gulf South. To tour the port, one can ride the Natchez, an authentic steamboat with a calliope, which cruises the Mississippi the length of the city twice daily. Unlike most other places in the United States, the city's historic cemeteries and their distinct above-ground tombs are attractions in themselves, the oldest and most famous of which, Saint Louis Cemetery, greatly resembles Père Lachaise Cemetery in Paris. The city and area boosts numerous museums and attractions of major interest and historical value. New Orleans ranked No. 7 on Newsmax magazine's list of the "Top 25 Most Uniquely American Cities and Towns," a piece written by current CBS News travel editor Peter Greenberg. In determining his ranking, Greenberg cited the city's rebuilding effort post-Katrina as well as its mission to become eco-friendly. The New Orleans area is home to numerous celebrations, the most popular of which is Carnival, often referred to as Mardi Gras. Carnival officially begins on the Feast of the Epiphany, also known as the "Twelfth Night". Mardi Gras (French for "Fat Tuesday"), the final and grandest day of festivities, is the last Tuesday before the Catholic liturgical season of Lent, which commences on Ash Wednesday. The largest of the city's many music festivals is the New Orleans Jazz & Heritage Festival. Commonly referred to simply as "Jazz Fest", it is one of the largest music festivals in the nation, featuring crowds of people from all over the world, coming to experience music, food, arts, and crafts.



ABRASIVE WEAR PROPERTIES OF THERMALLY STABLE DIAMOND COMPOSITE MATERIALS

J.N. BOLAND, X.S. LI AND C. HARBERS
CSIRO Energy, Queensland AUSTRALIA

Introduction

There are many parameters that influence the wear properties of diamond composite materials. Such parameters as manufacturing process, diamond grain size distribution as well as the addition of secondary phases that nominally act as bonding agents. The present study is focussed on characterising the specific class of diamond composites referred to as thermally stable diamond composite (TSDC) in which the binder phase is usually silicon carbide (SiC) and the manufacturing process involves the reactive sintering of the diamond phase with molten silicon metal via a carbide formation reaction that facilitates the bonding of the diamond grains. The exceptional wear resistance of TSDC as an abrasive wear resistant material has been shown in an earlier study. Further, with the development of TSDC, tools with these cutting elements are able to operate up to 1300oC which is much greater than the usual limitation of ~800oC of PCD (polycrystalline diamond) class of diamond composites.

Characterisation of Materials and Experimental Methods

The materials used in this study constitute an integral part of a much broader research program aimed at optimising the wear resistance and mechanical properties of thermally stable diamond composite materials for industrial applications. All samples were reactively sintered in the diamond stability field (1550oC, 5.5 GPa) by a commercial manufacturing company. The major sintering additive was metallic Si which, at these high pressure, high temperature (HPHT) conditions, melted and infused through the interstices in the diamond powder. The specifications of the specific subset of samples used in this study are given in Table 1 in which the composition of the samples is listed as the weight percentage of the starting granular phases (silicon and diamond).

Material Characterisation

All samples – both the starting powder mixes and the reactively sintered

Table 1

TSDC Sample ID	Nominal Composition[1] - Diamond/Si, wt %	Grain Size[2], microns
J7	85/15	200-400
J8	85/15	40
J9	85/15	28

1. Composition of starting granular phases prior to reactive sintering.
2. Dominant and identifying diamond grain size – see text for further comment.

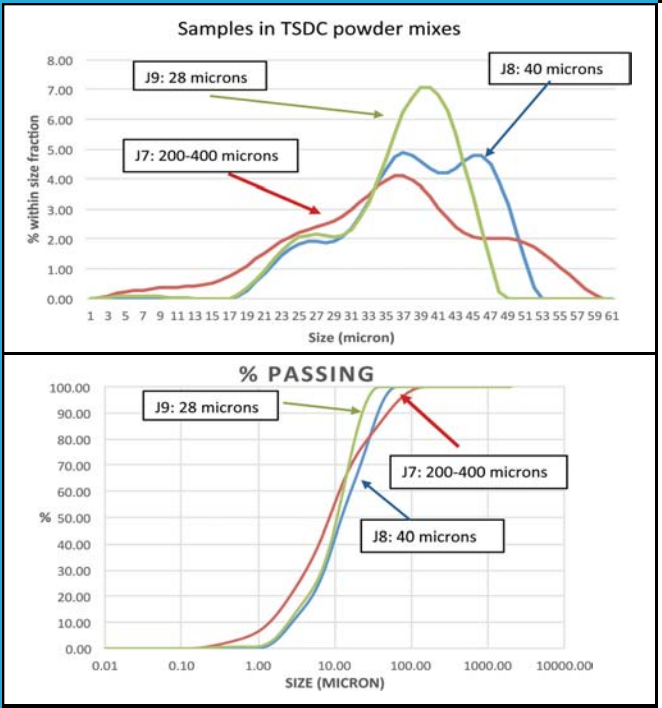


Figure 1: Results of particle analyses of the three powder mixes showing size distribution and percentage passing.

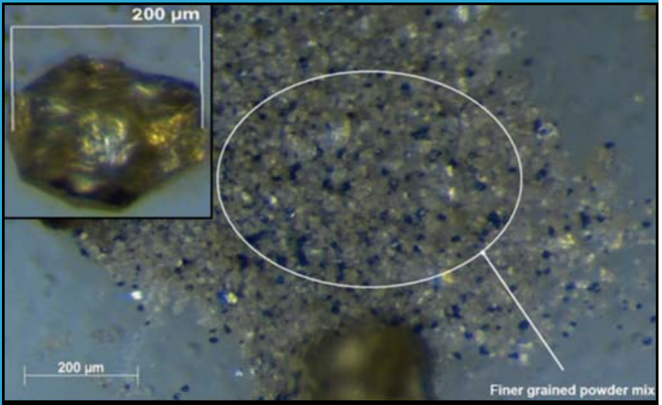


Figure 2: Optical micrograph of powder mix used to prepare sample J7. The insert shows one large diamond grain ~ 200 micron across.

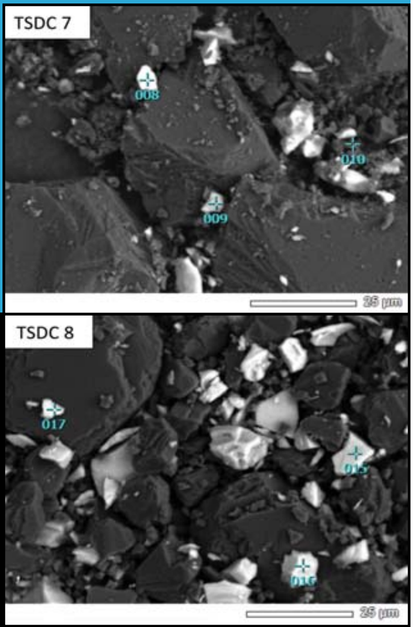


Figure 3: Backscattered SEM images (BEI) of the powders used for sample TSDC J7 and J8. All EDS spot analyses on these samples were identified at silicon grains; the darker contrasting grains were diamond.

products - were examined using (a) a Malvern Mastersizer 2000 laser system (starting powder mixes only), (b) optical microscopy (OM - Zeiss Discovery V8 Stereo microscope), (c) scanning electron microscopy (SEM – Jeol 6463 equipped with an energy dispersive system for compositional analysis (EDS)) and (d) X-ray diffraction methods (XRD) for specific phase identification (PANalytical Empyrean using a Cu X-ray tube). Phase identification and quantification of the powders and sintered products were made using PANalytical software, HighScore Plus, version 4.5.The fracture surfaces generated in the tensile tests were used in both the SEM+EDS studies and the XRD analyses. It is important to note that these surfaces were highly profiled and hence rough on the micron scale.

Particle Size Analysis and Phase Identification of Powders

Samples of the selected powder mixes were analysed using a Malvern Mastersizer2000. These results are shown in Fig 1. Clearly, the starting powders consisted of a wide range of grain sizes for all three samples used in this study. In order to assess the dominant diamond grain sizes, the powder samples were prepared by a small-scale elutriation procedure that enabled better separation of the constituent phases, leading to the exposure of the dominant diamond grains – Fig 2. For example, the manufacturer specified that for TSDC 8 the dominant diamond grain size of 40 microns. Clearly, from the SEM image in Fig. 3, the diamond (the dark phase in this backscattered electron image – BEI) grains ranged in size from a maximum of ~ 40 microns to a submicron component. The silicon grains were mostly in the sub 10 micron size range. A similar spread in grain sizes was also evident in TSDC 7 except that there was approximately around 5 % of the diamond grains in the 200-400 micron size range. Perhaps the more surprising result of the particle-size analysis was that there were no particles registered above ~120 microns in J7. However from optical microscopy examinations, large diamond grains up to ~300 microns were observed – see Fig. 2. It was difficult to obtain a truly representative sampling of premix powder used to produce J7 but clearly there was only a small proportion of the larger-grained diamonds in this powder mix. The particle analysis results showed a broad range in sizes.

Table 2: Phases Identified in Starting Powder Mixes Using XRD

TSDC Sample ID	Diamond	Silicon	Nickel	Graphite	Quartz	BN
J7 Powder Mix	85.9	13	0	0.4	0	0.8
J8 Powder Mix	88.1	11.6	0	0.2	0.1	NT
J9 Powder Mix	89.4	10.4	0	0.2	0.1	NT
Nominal Composition	85	15				

In order to identity the phases in the powder mixes, XRD studies were undertaken. Using the PANalytical HighScore software, the various phases were identified. Fig. 4 shows an example of the X-ray spectrum from the starting powder mix for J7. It was observed that small quantities of other phases were present in the samples, such as graphite (0.4%) and boron nitride (0.8 %). The major phases were diamond (85.9%) and silicon metal (13%). A summary of these XRD studies is shown in Table 2.

Abrasive Wear Rates and Tensile Strengths of Sintered TSDC Samples

The samples, which were in cylindrical format with a conic cutting tip, were mounted in the CSIRO wear testing rig following the method previously used. The wear rate was measured as the weight loss from the TSDC sample per cubic

Table 3

TSDC Sample ID	Grain Size, microns	Wear Rate, g/m^3	Tensile Strength, MPa
J7	200-400	16.6	80.6
J8	40	5	62.5
J9	28	9.3	38.9

meter of material machined from the corundum grinding wheel (properties: density: 2.18 g/cc; UCS: 120.7 MPa; tensile strength:19.8 MPa; Cerchar Abrasivity Index (CAI) 3.54±0.55 – Fig. 5. The tensile tests were performed on a 250 kN Instron testing rig using specially designed sample grips –refer Figs 6 and 7. The results of both sets of tests are shown in Table 3.

SEM Microstructural Observations of Fracture Surfaces

The fracture surfaces of J7 and J8 were studies in detail in order to decipher the possible causes of the noticeable differences between their respective wear rates and tensile strengths. The SEM-BEI microstructure in Fig. 8 from sample J7 shows a large diamond grain (point 013) with a prominent quartz grain (point 014) identified from the EDS spectrograph. There are other grains showing varying grey scales that have been also identified using the EDS mode as residual Si, and Ti-rich phases, possibly TiB2. Since all examined surfaces were fracture surfaces from the tensile samples, it was important to examine evidence of any decohesion at the diamond grain boundaries. As clearly evident in Fig. 9, the diamond grain boundaries appeared fully intact, indicating excellent bonding occurred during the reactive sintering of these diamond composite materials.

It is possible to display the elemental composition of specific grains using X-ray images as shown in Fig. 10 for elements C, Si, O and Ti. The spatial resolution of such images is limited in this operational mode. In the case of Si-containing phases, it is not possible to distinguish between residual Si and the bond-forming reaction phase SiC in such images. However, by using the spot mode (EDS analysis) these two phases are readily distinguished. The origin of the Ti component could possibly be a contaminant but it is suspected that small quantities of Ti may well have been introduced to further aid in the wetting of the diamond grains leading to better bonding. Unfortunately, there is evidence of oxidation of the Si phase to quartz (SiO_2) as shown in Fig. 8. The three unexpected phases, residual Si, SiO_2 and TiB_2, were also detected in the XRD analyses. The presence of B was also confirmed by preliminary observations using LIBS (laser induced breakdown spectrometry - SciAps Z-300 handheld LIBS analyser).

SEM observations of J8 produced similar phase distribution results – Fig. 11. The broad diamond grain-size distribution found the pre-mix powders was reflected in the sintered product. Fig. 12 is a high magnification of Region A highlighted in Fig. 11. The resulting EDS spectra from points 001, 003 and 004 were consistent with their being identified as Si, Si and SiC grains; Fig. 13 shows the X-ray maps of the same area as Fig. 12. As mentioned previously, all SEM observations were made on fracture surfaces. Hence only qualitative and tentative phase identifications were possible. In addition, for the smaller micron to sub-micron grains there was the possibility of X-ray excitation from surrounding grains. Hence, unique phase identification was not possible. Nevertheless, the phases identified using XRD are likely to correct.

Discussion

In the pursuit of better cutting elements for

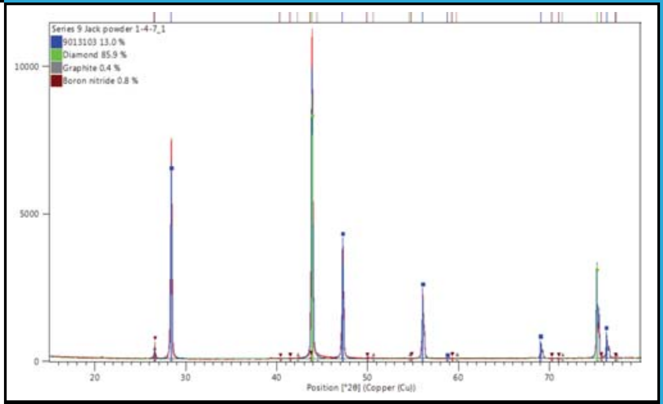


Figure 4: XRD trace of powder mix used to produce J7.

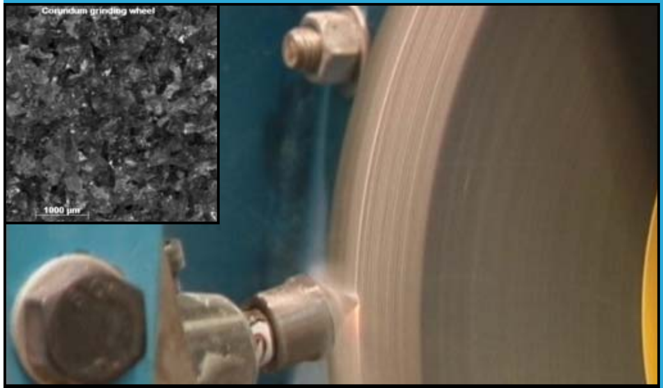


Figure 5: Abrasive wear testing rig. (left) optical micrograph of the corundum grinding wheel and (right) showing a TSDC sample cutting into the corundum grinding wheel.

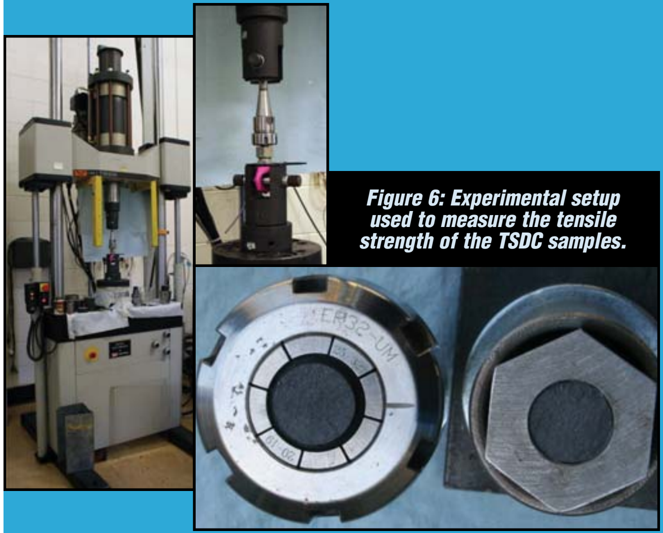
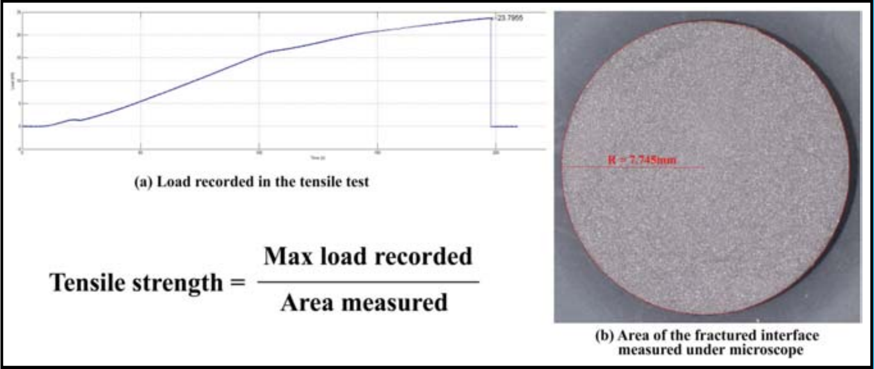


Figure 6: Experimental setup used to measure the tensile strength of the TSDC samples.



(a) Load recorded in the tensile test

$$\text{Tensile strength} = \frac{\text{Max load recorded}}{\text{Area measured}}$$

(b) Area of the fractured interface measured under microscope

Figure 7: Load-displacement graph and the fracture surface of the TSDC sample.

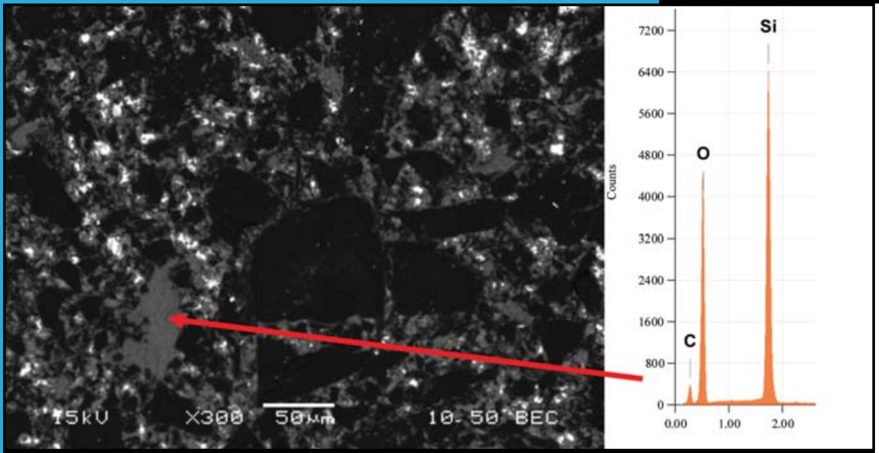


Figure 8: SEM backscattered image (BEI) from J7 (22) with diamond (dark grains) dominating the microstructure. EDS spectrum of the dark grey grain is consistent with it being quartz; the smaller, bright grains were identified as Ti-rich carbides.

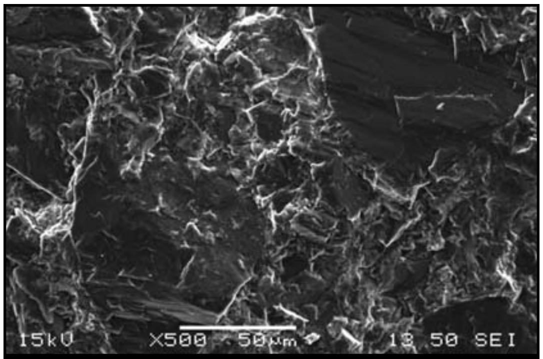


Figure 9: Secondary electron image (SEI) showing excellent cohesion at the diamond grain boundaries.

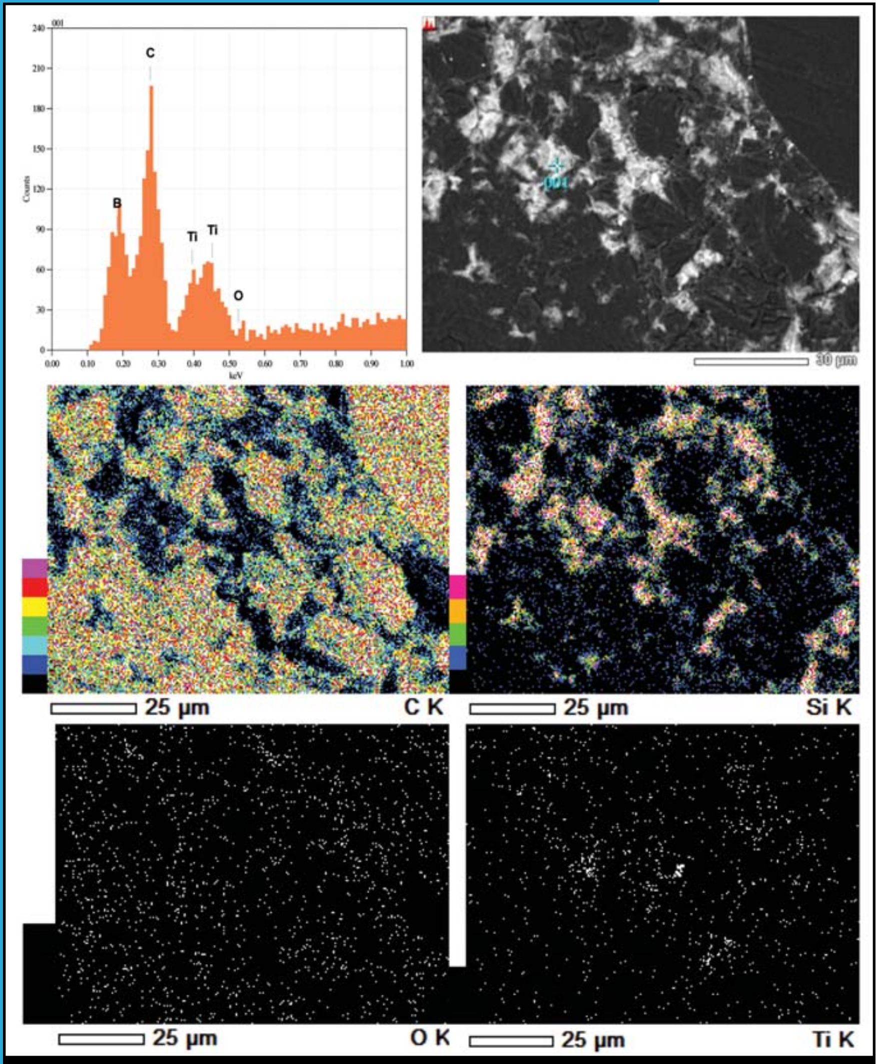


Figure 10: A composite figure showing an energy dispersive spectrum with a prominent boron peak derived from analysis point 001 in top-left SEM-BEI image from sample J7. The other images are X-ray maps showing the location of C, Si, O and Ti in the field of view

tools with applications in the mining and manufacturing industries, an extensive study of the properties of superhard diamond composite materials has been initiated by CSIRO over the past few years. The exceptionally low wear rates of such materials have made them the ideal materials for bonding into cutting tools across both industries. The standout feature of TSDC cutting elements is their suitability to operate under conditions where the temperature on the cutting interface may exceeds 800°C – an arbitrary, if not practical, temperature limit usually taken for PCD/PDC cutting elements. Previous studies have shown the TSDC cutting elements can operate successfully at temperatures of 1300°C or higher without any noticeable increase in their wear rate. One further outstanding advantage to the use of TSDC material is that, even when a significant wear flat has developed at the cutting surface, the tools will continue to function efficiently as the cutting element is a solid mass of diamond composite. This behaviour is in contrast to PCD/PDC cutting elements in which the composite coating is usually not more than 2 to 2.5 mm thick; once the wear exceeds that depth, the cutting element simply reverts to that expected of a cemented WC material which would rapidly wear under the highly abrasive condition encountered in most rock cutting operations. Based on the results of this study, it appears that it is necessary to compromise between optimising the wear rates and the tensile strengths. The lowest wear rates (5 g/m3) were achieved with the medium grain-sized diamond component (sample J8 – 40 micron nominal grain size) while the highest tensile strengths occurred with sample J7 which had the highest wear rate (16.6 g/m3) and contained the larger grain-sized diamond In a nominal range of 200-400 microns. These wear rate data appear contrary to the known behaviour of cemented WC materials in which the finest grain-sized hard phase (WC) had the lowest wear rate. In the TSDC material used in this study, sample J9 with the smallest grain size, given nominally as 28 microns, had the lowest tensile strength and an intermediate wear rate – see Table 3. With studies of cemented WC hardmetals, most researchers have used materials with much tighter control over the microstructural parameters such as grain size and grain-size distribution. However it is important to note that the wear rates of cemented WC hardmetals, having a broad grain-size distribution of the WC phase, were lower than that reported with material having much tighter control of the grain size. Further investigations of other parameters that may have important influences on the properties of TSDC materials are underway. Two important parameters under study are: (a) the influence of third or more phase additions that may improve the tensile and impact strengths without compromising the wear rate of TSDC and (b) tighter control over the grain size distribution of the diamond phase. ■

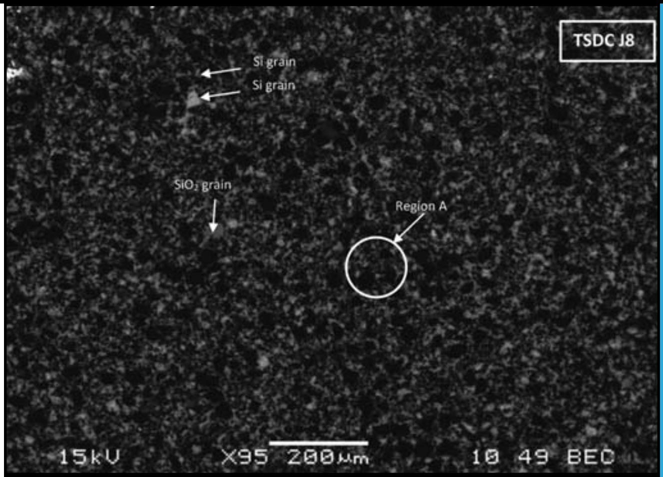


Figure 11: Low magnification SEM image in backscattered image mode (BEI) from fracture surface of TSDC 8 – refer to text for further details.

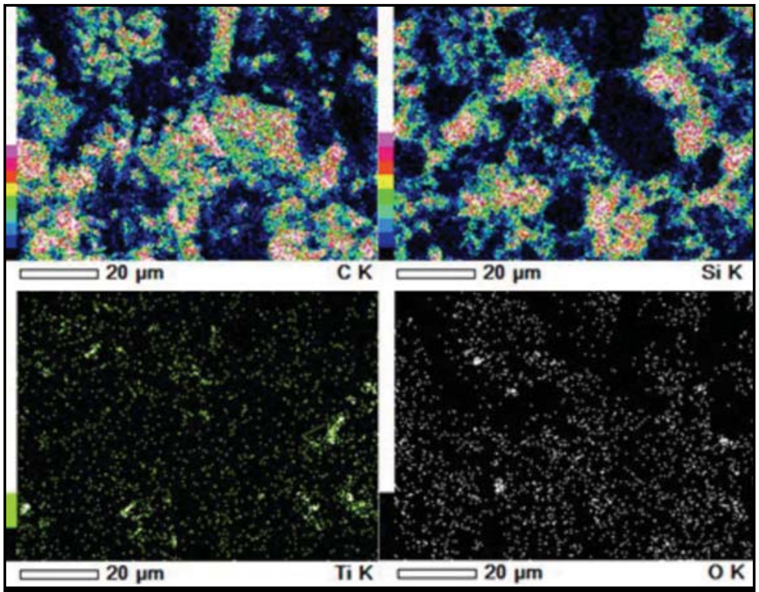


Figure 13: X-ray maps of the field-of-view in Figure 12. Note the present of Ti-rich and O-rich features – see text for details.

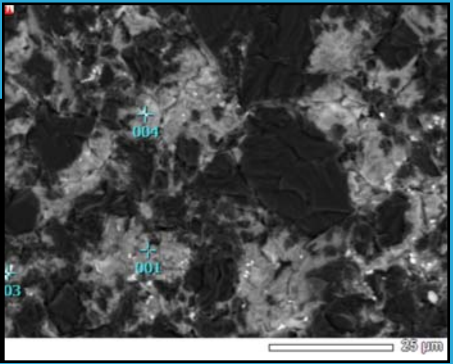


Figure 12: SEM-BEI micrograph of J8. EDS spectra at points 001 and 004 are consistent with these grains being residual Si while point 003 was identified as SiC.

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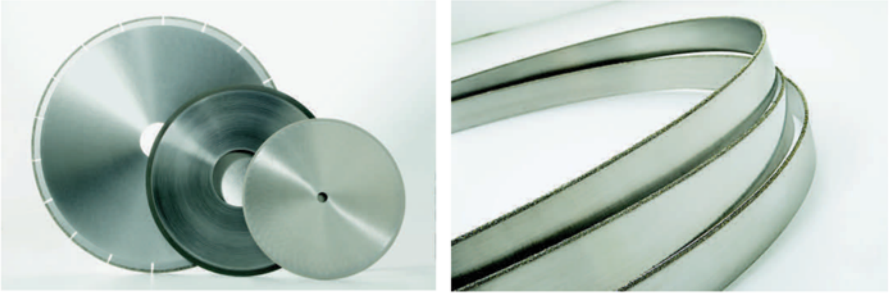
JOINT MEETING ANNOUNCEMENT

In a continuing effort to make the IDA Annual Meetings more user friendly in Non-INTERTECH years, the IDA Board of Directors with the approval of the General Membership have opted to change from a yearly Annual Meeting to a Biennial Meeting on alternating years with INTERTECH. The second meeting has been planned as a joint meeting with the Unified Abrasives Manufacturers Association (UAMA) at the Naples Beach Hotel and Golf Club and therefore we will share certain meeting and speaker events that are applicable to both Associations. During this meeting the IDA will also hold separate, focused business meetings and planning sessions for IDA events. Your attendance is an investment in the future success of your business and in our industry as a whole! With the tremendous success of INTERTECH Conferences and our education course, Superabrasive Materials, Principles and Applications, it is critical that all Members make an effort to participate. The IDA has surpassed our goals over the past few years and it is important that we continue this momentum with the active participation of our membership. This is the only time when we can all meet as suppliers, customers, competitors and colleagues to share in marketing goals and address issues that affect us all and all the industries we serve. Here is your chance to have a say in your Associations activities and share in that feeling of accomplishment for a successful Association! This Meeting will be held April 9 - 11, 2018 at the Naples Beach Hotel and Golf Club, Naples, Florida. Invited speakers will be Kirk Rogers, Ph.D., Technology Leader at the new GE Center for Additive Technology Advancement (CATA) to present: HOW GE'S 3D PRINTING PUSH WILL CHANGE MANUFACTURING", William Strauss, Senior Economist and Economic Advisor of the Federal Reserve Bank of Chicago who will present an "ECONOMY OVERVIEW AND FORECAST" and Daniel Pickard, Esq., Partner - Wiley Rein LLP an expert attorney who has handled related litigation to present "UNFAIR PRODUCT DUMPING IN THE SUPERABRASIVES INDUSTRY". These featured speakers will highlight an outstanding program that will also have an expanded Business Meeting covering ongoing projects and planning for events like the Superabrasives Education Course and INTERTECH 2019! NOW IS THE TIME TO MAKE THIS IMPORTANT MEETING, SO DON'T MISS IT!



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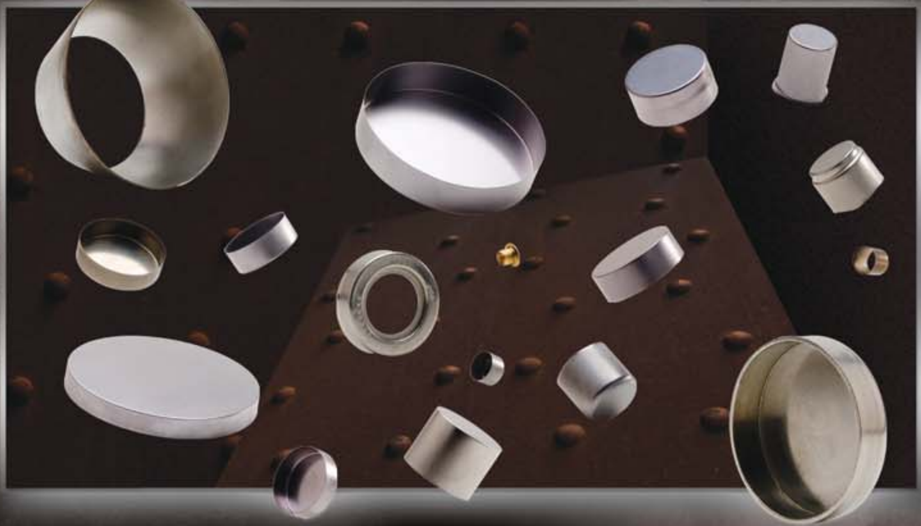

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